# ALGAE

*The Grass of Many Waters*

"The Weed Gatherers." Clew Bay, Connemara, Coast of Ireland. By T. R. Miles (the elder). About 1865.
(Courtesy Stanford University Museum).

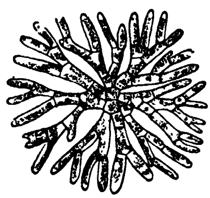
# *ALGAE*

## *The Grass of Many Waters*

*By*

Lewis Hanford Tiffany, M.Sc., Ph.D.

*Professor of Botany and Chairman of the Department of Botany, Northwestern University*



*Springfield, Illinois* • *Baltimore, Maryland*

CHARLES C THOMAS, PUBLISHER

To

E. N. T.

who first introduced me to algae

and to

L. Z. T.

who is willing to read my first drafts

of manuscripts

# PREFACE

WHEN WE try to picture the world in which we live, we think of men and women, dogs and cats, birds and airplanes, landscapes of green plants, houses and factories, sunshine and rain, and many other things. But such a world is *our* world: the world of the human species.

What do you suppose the eagle considers as his world? Did you every try to picture to yourself the monotonous lack of variability in the subterranean tunnel that constitutes the darksome universe of the mole? The larva of a California fly lives in pockets of crude oil. Species of mold have been known to grow and reproduce in formaldehyde. Some bacteria are apparently unharmed by cooling to the temperature of liquid hydrogen (−252° C). Shocking, isn't it? Somebody like Lewis Carroll or Jules Verne or perhaps even Mr. H. G. Wells should have written a series of booklets on the cosmos as "seen," say, by a gnat, by an elephant, by a worm, by a fish or by a frog. It would be such fun to read them.

If the author of this book were a fish or a frog, he could doubtless write a very entertaining account of the algae: at least it would be different. That a fish would describe an alga as a "low form of plant able to manufacture its own food" is quite uncertain indeed. Whether or not a frog would approve of such epithets as "pond scums," "frog spit," "that green moss," or "plant debris" is very much unknown. Really, I suspect, a fish—a little fish anyway—generally regards many of the algae as great stationary or oscillating forests of intertwining, variously colored, slippery, slimy strands through which it must swim in hunting for its breakfast or in dodging another hungry fish. At some time during its life, however, the average fish must regard algae as a rabbit considers lettuce, as a horse enjoys green pastures, or as Rastus thinks of watermelons: in other words, as something to eat.

But then this book is being written—unfortunately you

may say—by a species of the genus *Homo*, not by a fish. Perhaps it is just as well, considering this fact, to abandon any idea of understanding algae as seen by a fish and try to analyze what man knows about these plants.

The author has been interested in algae for nearly twenty-five years now, and he has been asked a great many questions about them by students, by the general public, and by specialists in other sciences. He hopes to be able to reply to some of these queries in the following pages. The book is not written for those who already know all about the algae. Such individuals are requested to read no further: they will find nothing new. *Nullum est jam scriptum quod non scriptum sit prius.*

L. H. TIFFANY

*Evanston, Illinois,*
*August 1, 1937*

## ACKNOWLEDGMENTS

ADEQUATELY to make full acknowledgment to those responsible for one's ideas is quite impossible; even an attempt is futile. Just when the genosome postulating an interest in algology entered my ancestral chromosomes I have no means of ascertainment. Why the interest expressed itself in me, instead of my mother or father or brothers, I cannot explain. To state it more simply: of the hereditary aspects of this case I know nothing.

Although it pains me most grievously, I must apparently ally myself for the moment with the still-too-numerous run-of-the-mine social workers, sociologists, psychologists, and ministers who imagine themselves beholden only to environmental influences and who consequently pooh-pooh everything that smacks of hereditary predeterminism. It is necessary, it seems, to ascribe my interest in algae purely to environment. The environment has been, to be sure, biotic: contact first with one man and then others who already had a healthy interest in aquatic plants.

To these men and women whom I have known either personally or through their writings I am profoundly grateful. By specific mention of none I can therefore include all.

* * *

References at the end of the book furnish added and more complete data for those who are interested in further pursuit; they are general in scope, and some of them contain excellent bibliographies to algological literature.

* * *

Some of the illustrations are borrowed from various sources, and proper credit is given in each case. Text figures 1–12 were executed by Celeste Taft. The remainder of the illustrations, unless otherwise indicated, are by the author.

## CONTENTS


Page

PREFACE . . . . . . . . . . vii

ACKNOWLEDGMENTS . . . . . . . . . . ix

I: WHAT ARE ALGAE? . . . . . . . . . . 3

Green scum in August; a microscope in every home; algae *vs.* grass; what one may see under a microscope; plants *vs.* animals; variations in algae: size, productivity, habitats, pigmentation.

II: ALGAE AND THE FOODS THEY MAKE . . . . . . . . . . 13

Necessity of food for living organisms; making of carbohydrates, fats, and proteins by algae: raw materials, solar energy, chlorophyll, elaborated foods; oil and starch in *Vaucheria;* foods of various algal groups; foods of plants and animals.

III: HOW ALGAE GROW AND REPRODUCE . . . . . . . . . . 21

Foods and growth of algae: respiration and assimilation; dormant spores—dead or alive? germination of algal spores; results of cell division in *Spirogyra, Oedogonium, Ulva, Cladophora, Merismopedia, Eucapsis,* diatoms; akinetes of *Pithophora* and continuous artificial illumination; cell differentiation; some types of reproduction in algae.

IV: ALGAE OF LAKES AND PONDS . . . . . . . . . . 37

The aqueous cosmos and unlovely nature; ponds *vs.* lakes; water blooms; plankton; availability of light for aquatic organisms; the spectrum; measuring light in water; necessity of light; algae of different depths; temperature; algal periodicity; types of lakes; carbon dioxide and oxygen; mineral salts; pH; lakes and ponds considered biologically.

V: ALGAE OF STREAMS AND RIVERS . . . . . . . . . . 57

River systems; algal productivity of running waters: attached algae and plankton; "catches" of algae; algal populations and part played by tributaries; an environment of great variability and fluctuation.

VI: ALGAE OF THE SEA.......................... 65

The land and the sea; volume and depths of oceans; the "Sargasso Sea"; the algal productivity of the sea: its chemical elements and compounds, its temperature, its zonations, its seaweeds, the algae of great depths, the plankton; some examples of marine algae: appearance, growth, habitats, and reproduction; the primary food supply of the sea; diatomaceous earth; the sea a colossal ecological complex.

VII: ALGAE OF THE SOIL.......................... 83

Man's vested suzerainty; bacteria, fungi, protozoa, and algae; surface and subsurface algae; culturing soil algae; algal productivity of soils; algae and nitrogen fixation; soil algae as a definite flora.

VIII: ALGAE OF ICE AND SNOW.................... 90

Wastes of ice and snow; algae and subzero temperatures; flora of perpetual ice and snow; growth of Cryoalgae; fat compounds "adaptations" to cold; dormant algae and low temperatures; red snow, yellow snow, green snow, and black snow; ice and snow as algal habitats.

IX: ALGAE OF BIZARRE ABODES.................. 96

Algae in many environments: free floating and attached, epiphytic, aerial, epiphyllous to parasitic, endophytic, symbiotic, epizoic, endozoic; from duckweeds to magnolias, from water-fleas to man.

X: ALGAE OF THE PAST.......................... 108

Speculative man; age of the earth and how calculated; first living organisms; how fossils are made; geological time table; algae of the Archeozoic, Proterozoic, Paleozoic, Mesozoic, and Cenozoic; Seward's Ordovician and Devonian seas; fossil diatoms; relative constancy of water habitats.

XI: ALGAE AND HUMAN WELFARE................. 126

Have algae any value? noxious algae: limiting photosynthesis, contaminating water supplies, depleting oxygen supply at night, injuring fishes; removing algal growths by copper sulfate, by sodium arsenite, by proper drainage, by crayfish, by mechanical means; benefits of algae: food of fishes and other aquatics, indirectly as food for higher animals and man, energy value; economic value of kelps and other marine algae; digestibility of algae; chemical composition of algae; algae and ice cream; algae and research.

XII: HOW TO COLLECT ALGAE. . . . . . . . . . . . . . . . . . . . . . 146

Importance of knowing where algae grow and their seasonal appearance; a collecting trip: equipment needed; living townets: gizzard shad and tadpoles; preserving algae; herbarium specimens; special collecting devices.

XIII: HOW TO STUDY ALGAE. . . . . . . . . . . . . . . . . . . . . . 155

Necessity of microscope: limitations of human eye; equipment necessary; how algae are classified; initial study by emphasis on genera; Latin names and common names; manuals, keys, descriptions, and figures; man as a collector of things.

GENERAL REFERENCES . . . . . . . . . . . . . . . . . . . . . . . . 163

INDEX . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165

# ALGAE

*The Grass of Many Waters*

## Chapter I

# WHAT ARE ALGAE?

MY FIRST experience with algae—though heaven knows I did not know such a word then—was a suggestion from my father regarding swimming during the "dog days" of August in southern Illinois. And when my father made a suggestion, I knew exactly what to do. At that time I had not heard (and neither had my father) of the educational theory that frowns on external regulation of the behavior of a child. Father's words were few: "When there's green scum on the water, that is a sign of dog days; don't go in swimming."

My next encounter and really the beginning of a healthy interest in these aquatics came when I was introduced to a wholly new and an almost unbelievable world through glances into a microscope. If it were not for the danger of being accused of lobbying for some optical company, I should like to recommend a new slogan for America: *a microscope in every home.*

This book has been called *Algae, the Grass of Many Waters.* It must be admitted at the outset—for fear that some of our botanical experts, who countenance no license in the use of terms, may laugh at us—that algae are not really grass at all. Taxonomic botanists do not hesitate to call wheat and corn and timothy and even bamboo "grasses," but we are not allowed to include the algae. Why? Well, it seems that a plant must have certain characteristics—*grass* characteristics, if you please—before it can be a grass: grass seed, grass leaves, grass stems, grass flowers, and grass roots. Algae have none of these. On the other hand, algae are to fishes and other aquatic animals what grass is to horses and cows and giraffes. Perhaps it is a bit inconsistent, but for all we know the fish may think that an alga is a grass. Suppose that we let it go at that.

PLATE I. Fishes-eye view of an algal forest: *Oedogonium*, *Draparnaldia*, *Spirogyra*, *Vaucheria*, *Microspora*, and *Ulothrix*. (From Transeau: *General Botany*, copyright 1924 by World Book Company.)

Algae are among the most interesting plants in the world. If you don't think this is so, try out a little experiment. After the warm spring days have had a chance to remove most of the remnants of winter, visit a pond in your neighborhood and bring to your home a gallon of water. If the water has some scarcely visible strands or clumps of green plants in it, so much the better. Pour the water into a glass container and set in a mediumly lighted window. If you own a microscope (if you don't, borrow one), put some of the water on a slide and examine it through the lens. What do you see?

There may be green and yellow balls darting here and there with seemingly lightning-like speed. Green flat plates may make clumsy arcs and circles while you look. Tiny yellowish boats may zigzag ever so slowly, producing at the stern a slimy ooze. Every now and then there may be a head-on collision between a couple of the more rapidly moving forms. Nobody is ever injured in such traffic jams, and many of these autoplants can travel backwards as well as forwards; in fact, some of them may have furnished the idea for our new streamline models of automobiles: the rear looks just like the front. Then you may see globular or heart-shaped or even irregular clumps of blue-green balls. Some of the slowly rolling or slightly moving plants have no means of locomotion except as some passerby creates a disturbance in the water.

Perhaps you are a bit confused now. Do you think we have made a mistake in naming these moving forms *plants?* Some people (even some scientists) have what is known as pigeonhole minds; that is, they are greatly disturbed if they are not able to classify any living creature as either a plant or an animal. The truth of the matter is that the words "plants" and "animals" are very, very old. They were used originally to separate trees from horses, weeds from grasshoppers, and grapevines from snakes. Microscopes were later invented and through them organisms hitherto unsuspected were seen. These microscopic forms are not always as easily separable one from the other as are trees and horses. Many of them have both plant and animal characteristics, and the name

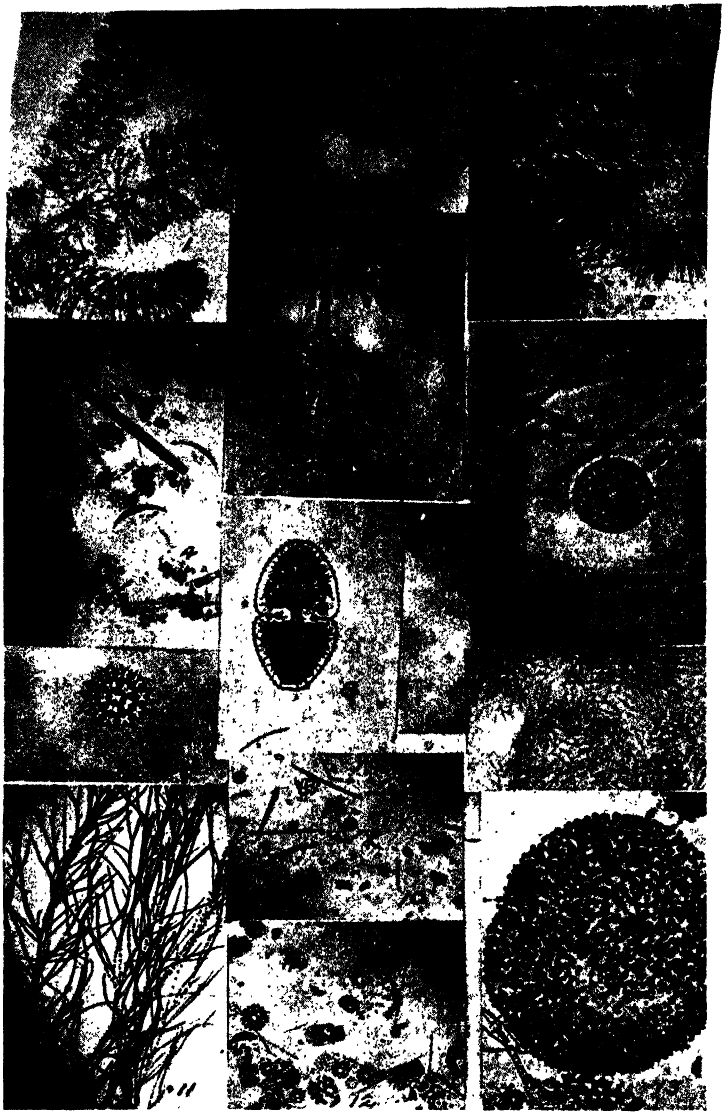


PLATE II. Glimpses through a microscope: 1, *Batrachospermum;* 2, *Asterionella;* 3, Three colonies of *Rivularia;* 4, Group of desmids (*Pleurotaenium, Cosmarium,* and *Closterium*) and small portion of *Oedogonium;* 5, *Ceratium;* 6, *Stephanodiscus* and *Fragilaria;* 7, *Pediastrum;* 8, *Cosmarium;* 9, *Dinobryon;* 10, Group of diatoms; 11, *Stigeoclonium,* an algal "grass"; 12, *Pediastrum, Platydorina, Crucigenia;* 13, Colony of *Microcystis.*

*Protista* has been suggested for them. This is merely another pigeon-hole and does not really solve the problem. For the time being then suppose that we do not further tease ourselves by trying to make plants or animals out of these aquatics. Many of them are plant-like and we name them algae. Later on we can return to this matter of classification.

But to continue our observations on the pond water through the microscope: there may be long silk threads of green or blue-green so slippery that you can scarcely hold them in your fingers. Under the microscope they glide over each other like so many green snakes. If besides the pond, you have time to visit a creek too, you may find long strands of green or blue plants attached to weeds and stones. Some of them branch and rebranch thousands of times, and since they are attached at one end only they look like miniature streamers rhythmically waving with the current. On the larger algae may be smaller algae, and on these still smaller ones.

If you live along the ocean, you will find many red and brown sea algae growing with the greens and the blue-greens. Some algae are accustomed to a life in salt water, and in fact if grown in aquaria the water must have a salinity similar to that of the ocean. Some of the marine algae are known as seaweeds and a few of them attain considerable size. Rocky cliffs in shallow water may be entirely covered with slimy growths of various kinds of algae.

All such plants and many others are algae. Some are so small that even a copepod finds it difficult to see them—if a copepod can see. These forms, however, may become so numerous in a body of water as to give it a decidedly green or yellowish-green color. And this color is what disturbed my father, resulting in the edict of no swimming during dog days. Many other algae are visible to the human eye and may at times grow and reproduce with prodigious rapidity. Some of the forms that are found in the oceans may reach a length of many feet.

The algae represent as wide a range in size as found in any other group in the plant kingdom. Some of the giant kelps,

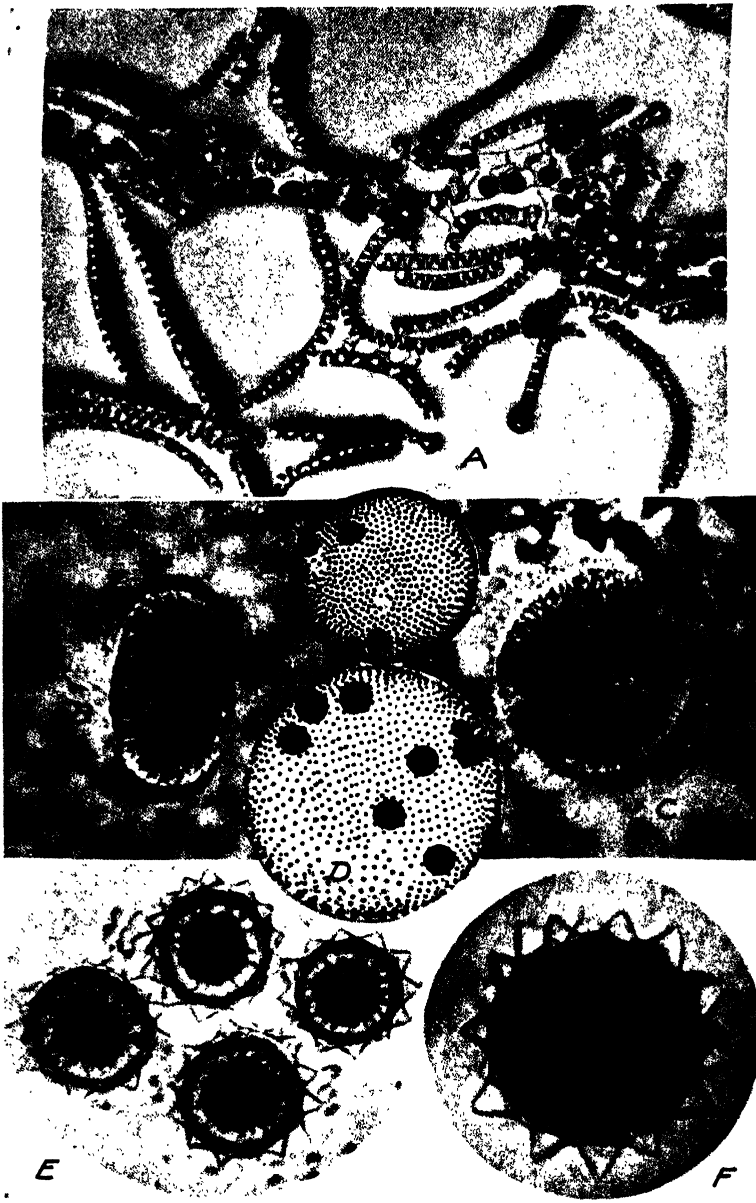



**Plate III.** Glimpses through a microscope: A, *Spirogyra*, vegetative and conjugating filaments; B, C, Packets of sperms of *Volvox;* D, Two colonies of *Volvox*, showing spores and vegetative cells; E, F, Oospores of *Volvox*. (A, from Czurda; B-F, from Rich and Pocock.)

which grow in marine waters, attain lengths well over a hundred feet. The leaf-like blade may be a few feet in diameter. Statements were current two or three decades ago that the kelps often grew to be over a thousand feet long. Such extreme lengths have never been verified. The surface area of a giant kelp is on the order of 6,000,000,000,000 times that of one of the minutest of the algae.

The smallest of algae measure scarcely a micron in diameter; that is, 25,000 of them side by side extend no further than an inch. Some 200,000 of them could lie on your thumb nail at one time. To put it another way, a pint cup could hold about 1,000,000,000,000 of them. At the height of their growing season there may be as many as 1,000,000 individuals of a single species in a liter of pond or lake water, and the amazing number of 7,000,000 individuals per cubic centimeter of water has been reported. The significance of this harvest will be discussed later.

Algae inhabit both fresh and salt waters. They flourish in ponds, in streams, in lakes, in warm springs; they hang from cliffs and cataracts. Other plants and even animals carry them both externally and internally. They grow on trees, in the soil, and on arctic snow. With very few exceptions they have chlorophyll and so are not to be confused with bacteria and fungi. They never have such well-defined organs as leaves, stems, roots, flowers, fruits, and seeds. Neither are algae the same as mosses or liverworts or ferns.

In the matter of pigmentation* perhaps no other group of plants exhibits so many different colors. The common names applied to the various classes of algae—greens, blue-greens, yellow-greens, browns, golden-browns, reds—merely represent what is commonly the manifest color of the plants. This really gives little clue to the possible color changes during the normal growth of algae belonging to any of these groups. The

* Some of the pigments found in algae and their chemical composition are: chlorophyll a, $C_{55}H_{72}O_5N_4Mg$; chlorophyll b, $C_{55}H_{70}O_6N_4Mg$; carotin $C_{40}H_{56}$; xanthophyll, $C_{40}H_{56}O_2$; fucoxanthin $C_{40}H_{56}O_6$; phycoerythrin, chemical composition unknown, thought to be allied to proteins.

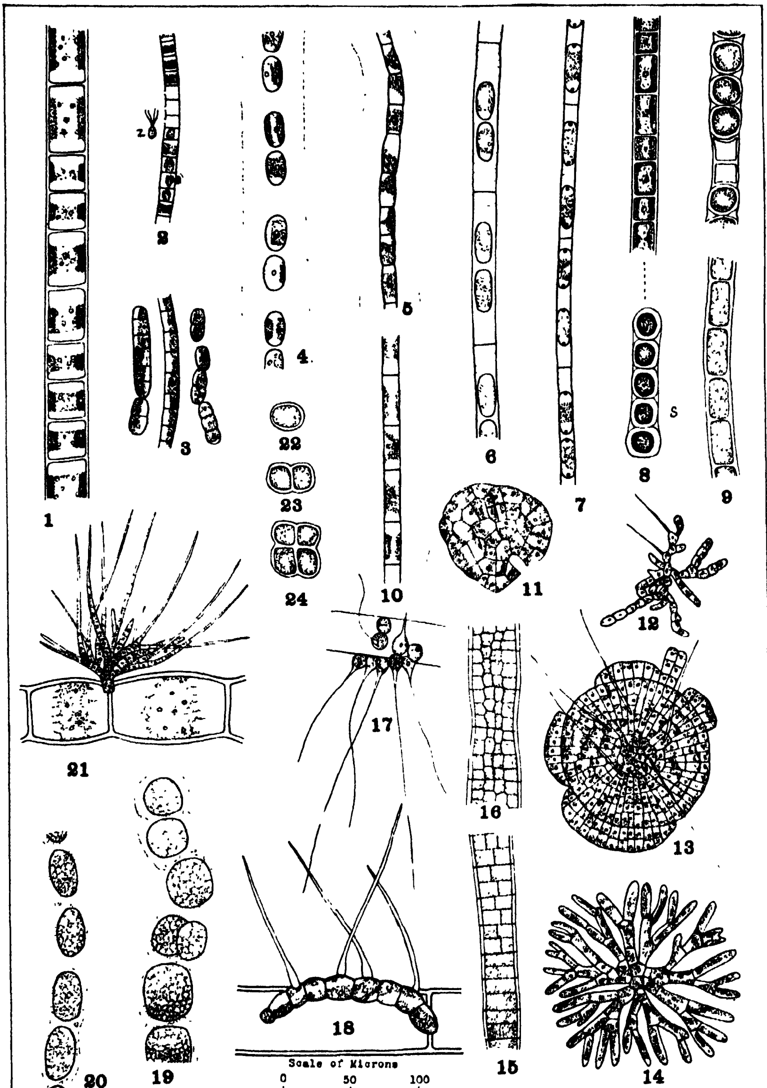



PLATE IV. Algae are of many shapes and forms: 1, 2, *Ulothrix*; 3, *Stichococcus*; 4, 5, *Geminella*; 6, 7, *Binuclearia*; 8–10, *Microspora*; 11–14, *Coleochaete*; 15, 16, *Schizomeris*; 17, *Chaetosphaeridium*; 18, *Aphanochaete*; 19, 20, *Cylindrocapsa*; 21, *Draparnaldia*; 22–24, *Pleurococcus*. (8, 9, 21 redrawn from Hazen.) z, zoospore; s, resting spore.

greens, for example, may be vivid green when actively growing and nearly yellow or brown during spore formation. The blue-greens perhaps supply the widest range of color. Sometimes the color appears to be fairly constant and at other times quite dependent on environmental conditions. One might even coin a new name and call the blue-greens the rainbow algae.

TABLE 1. DISTRIBUTION OF PIGMENTS IN THE ALGAE

| Classes of Algae | Common Names | Chlorophyll (green) | Xanthophyll (yellow) | Carotin (orange) | Phycocyanin (blue) | Phycoerythrin (red) | Fucoxanthin (brown) | Accessory pigments (brown, red, etc.) not well known |
|---|---|---|---|---|---|---|---|---|
| Chlorophyceae | Greens | x | x | x | | | | |
| Xanthophyceae | Yellow-greens | x | x | x | | | | |
| Diatomophyceae | Diatoms | x | x | x | | | | x |
| Chrysophyceae | Golden-browns | x | x | x | | | | x |
| Dinophyceae | Dinoflagellates | x | | x | x? | | | x |
| Euglenophyceae | Euglenas, etc. | x | | x | | | | x |
| Phaeophyceae | Browns | x | x | x | | | x | |
| Rhodophyceae | Reds | x | x | x | x | x | | |
| Myxophyceae | Blue-greens | x | | x | x | x | | |

The following colors and shades of color may be observed in them: red, rose, orange, yellow, green, blue, blue-green, purple, brown, violet. In fact the origin of the name, Red Sea, is traced to the occasional abundance of a red alga belonging to the blue-green group.

The variation range in the algae is among the greatest in the plant kingdom. They may be unicellular or pluricellular. The colonial forms may have definite shapes, or they may be merely irregular aggregates of cells. The cells may be spherical, cylindrical, club-shaped, spiral, sigmoid, wedge-shaped, or even amoeboid. The plants are filamentous or plate-like, branched or unbranched, free-floating or attached, micro-

scopic or macroscopic, highly ornamented and sculptured or smooth, annuals or perennials.

Such are the citizens of the algal kingdom: their number is legion; their abodes are many; their patterns are varied; they are largely our friends. We may name all of them, in spite of their dissimilarities, *Algae*.

## CHAPTER II

# ALGAE AND THE FOODS THEY MAKE

THE PRESIDENT of a midwestern teachers' college once remarked to the students that ". . . of the head or stomach, the latter is more important." To many poets and philosophers and theologians who must, because of some of their basic assumptions, frequently deal in a world of make-believe, such a statement doubtless sounds materialistic, earthy, or even base. Yet this same president was learned in classical poetry, was a very wise philosopher, and was a profound student of sacred literature.

What the gentleman had in mind, I suspect, was that food is an absolute necessity for everything we think or say or do. It is quite true that nobody—unless it be Arthur Guiterman—ever thinks of writing sonnets about the gastric juice or goes into poetical ecstasies regarding the inspirational value of a steak smothered in onions.

Apparently to digress from this thought but in reality to extend its implications, let us think about the fishes and the myriads of other hungry animals that inhabit the waters of lakes and streams and seas. We can scarcely say that food is the only item of interest to these aquatic animals (for who knows what their interests are?) but we can be sure that food is the prime requisite for their very existence, the *sine qua non* of life itself.

Although it was brought out earlier that our friends the taxonomists will never consent to our thinking of algae as grass, yet in a most important characteristic they are identical. There occurs in each a green coloring matter, made up of carbon, hydrogen, oxygen, nitrogen, and magnesium, that is known as chlorophyll. To be sure, many algae and the grasses too contain other pigments, but just now our interest lies in

the chlorophyll. At the risk of appearing dramatic we may truthfully say that chlorophyll is the most important substance in the world. It is worth more than money. It is as indispensable as air or sunshine or water. All of the world of both plants and animals must soon cease to be if deprived of this green coloring matter. The reason is not far to seek: no chlorophyll, no food; no food, no life.

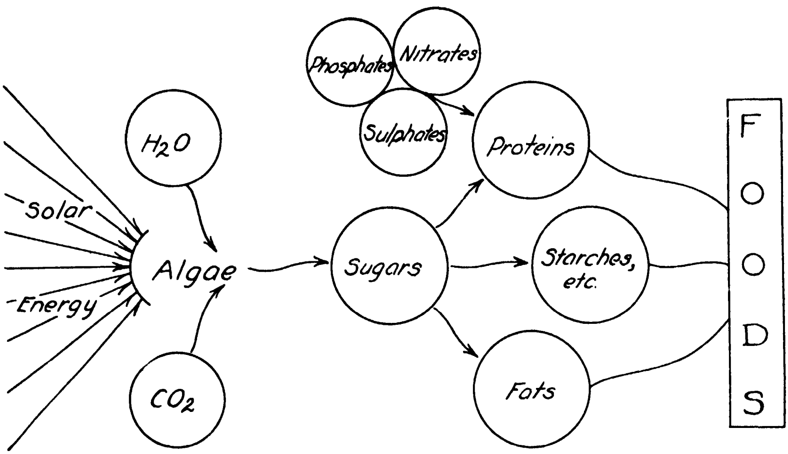



FIG. 1. The foods that the algae make are the same as those made and used by other green plants and the same as those used by you and me.

The modern dreamer who likes to look forward to a world directed by a Buck Rogers, a Wilma Deering, and a Doctor Huer does not approve of the exalted position to which chlorophyll is elevated by the botanists. To him chlorophyll is merely a compound which may some day be made in a chemical laboratory. Foods may then be small pills of greatly concentrated energy, and the habitated planets may forthwith dispense with green plants. We of the present age, however, shall hardly witness this chemical millennium and must take things as they are. So let us study chlorophyll some more.

The algae (the same is true for grasses and thistles and pines and artichokes, but this book *is* about the algae) have been carrying on for centuries a chemical process that is no

less amazing than the alchemist's dream of turning lead into gold. The process eventuates only through the action of the chlorophyll. In this green pigment under suitable temperatures and light, a gas (carbon dioxide) unites with a liquid (water) forming a solid (sugar) and another gas (oxygen). The chemist likes to represent it this way: $6CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$. The technical name of the process is photosynthesis, and the life of the waters is dependent upon it (Fig. 1).

Sunlight supplies the energy necessary to tie together the atoms of the elements present in carbon dioxide and in water into sugar. The chlorophyll itself appears to develop best in the yellowish-green, green, and bluish-green areas of the spectrum and least in the infrared and ultraviolet rays. The absorbed regions of sunlight under suitable conditions make possible sugar formation in the algae. Why is this so? Nobody knows. The chlorophyll in a way not clearly understood absorbs a sufficient number of the right kind of light rays and makes them available in the sugar synthesis. No other compound has this unique property.* It is true that Baly, the English chemist, has artificially made a very small quantity of sugar. This is practically insignificant in its present stage of development, although it may indicate preliminary steps in the elucidation some day of another of nature's innumerable enigmas.

It may be remarked that if we examine algae chemically we may find little sugar, as such, in many of the cells, although sugar is usually demonstrable in actively growing algae. Why then bother about all this emphasis on chlorophyll and photosynthesis? The answer is quite definite, although some algae make certain chemical compounds that present a Sisyphean task to account for their origin.

A little experiment will enable us perhaps to see somewhat

* We are here omitting any reference to certain colored sulphur bacteria, comparatively insignificant as food producers, which utilize solar energy in a kind of photosynthetic process through such pigments as bacteriopurpurin and bacterioviridin.

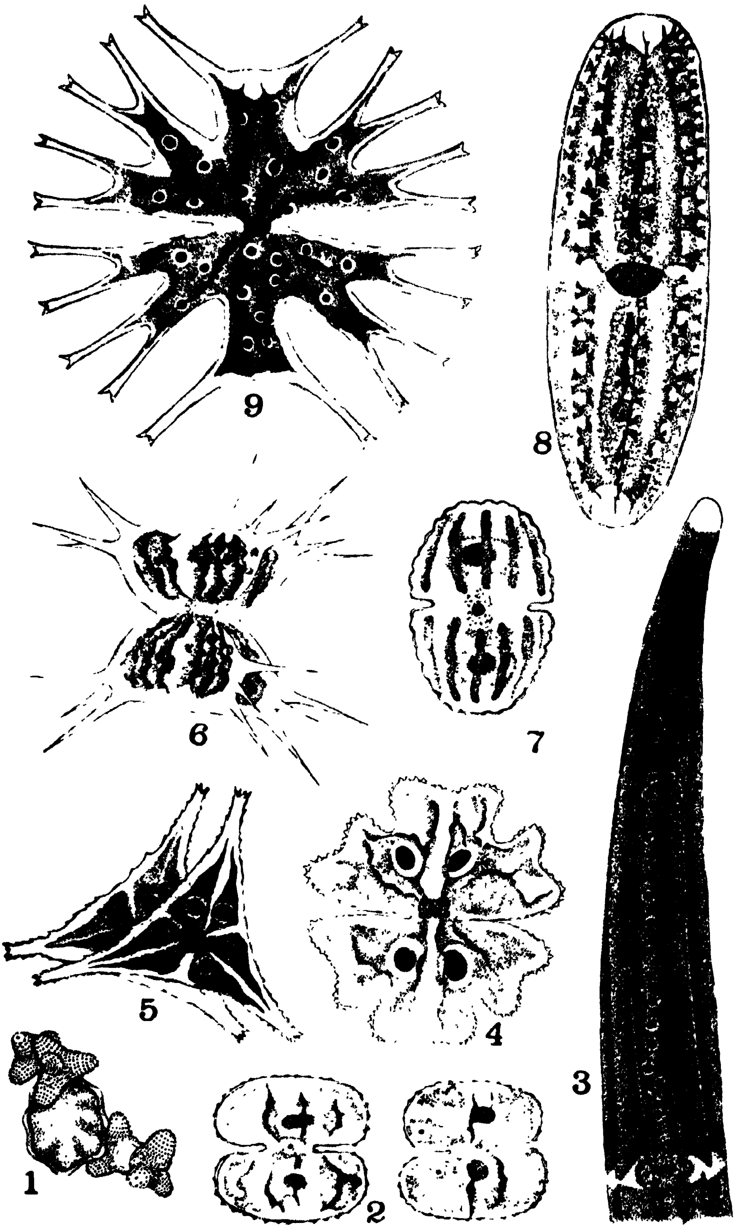


**PLATE V.** The chloroplasts of desmids are varied: 1, sexually formed spore of *Staurastrum*; 2, *Cosmarium*; 3, *Closterium*; 4, *Euastrum*; 5, 6, *Staurastrum*; 7, *Cosmarium*; 8, *Netrium*; 9, *Micrasterias*. (1, from Skuja; the remainder from Carter).

more clearly just what this problem is. If a drop of iodine be placed on a microscopic slide containing some algae, such as *Spirogyra* or *Oedogonium*, a blue color will appear in spots in the cells. The coloration results because of the presence of starch. By carefully dissolving away the starch spots, we come upon a core of material not affected by the iodine: we call the substance protein. This kernel of protein surrounded by a starch sheath forms a so-called pyrenoid, but we shall hear more about it later on. In another alga, such as a diatom or a *Spirogyra* spore, may be globules of oil. Such compounds—starches, fats, and proteins—are the foods of the algae. What is their source?

Our best evidence seems to be that starches and fats and proteins are made in the algae out of sugar. For the chemically minded we may indicate in general terms just how this occurs. The change of sugar into other foods occurs in the protoplasm at any time, and chlorophyll is not concerned except for the necessity of a replenished sugar supply. The sugar molecules lose molecules of water and then we have molecules of starch: the chemist calls it condensation; the biologist may think of it as starch synthesis. Now before the algae use the starch it must be changed back into sugar. This is exactly what happens in our bodies, and we call it digestion.

In the making of fats the sugar first undergoes a diminution of its content of oxygen in relation to hydrogen and forms glycerine and fatty acid: this part of the process is known as a reduction. The union of the fatty acid and the glycerine with a loss of water (another case of condensation) forms a fat (Fig. 1).

To make proteins out of sugar the algae must have available mineral salts containing nitrogen, sulfur, and sometimes phosphorus. The absence of these elements is why algae die in an aquarium in which distilled water has been used. Nitrates, nitrites, and ammonium salts are sources of nitrogen, although the two latter are less favorable. Potassium phosphate and magnesium sulfate are sources of phosphorus and

sulfur.* Through another reduction process the sugar and the nitrogen and in some cases the sulfur form an amino acid. Some of these amino acids the fishes must have for scales and fins and for growth and reproduction, but they can't for the life of them make them. The algae can, however, and the fishes eat the algae. Some people have indicated that a fish eats algae to get these amino acids; but this is absurd: the fish eats the algae because it likes them. Of course it *is* a good thing for the fish that the amino acids are there, although he doesn't know it. But to get on with the making of proteins — when two or more amino acids unite with a consequent loss of water, a protein is formed (Fig. 1). Sometimes phosphorus is concerned in this process, particularly in the formation of the so-called nucleo-proteins. The number of molecules of amino acids making up a molecule of protein varies perhaps from one hundred to several hundreds.

For those of you who are mathematically inclined, the amino acids and the proteins furnish a nice little problem in figures. Some twenty-two amino acids are now known by the biochemist, and a protein apparently may be made out of any two or more of them. How many kinds of proteins are then possible? Somebody solved it and claims that the number amounts to 10 with 47 ciphers after it. It is not known how many kinds of proteins are formed in algae, but the total number known to the biochemist is not more than 500.

Before we go further, we must confess that we do not know everything about the food of the algae. In such forms as *Vaucheria* and in a whole group of algae known as yellow-greens, carbohydrates are usually lacking, although the cells may be full of oil. This might indicate that these fats are not made out of sugars or other carbohydrates. There is, however, a much simpler explanation, though the evidence is not always completely convincing. I once exposed *Vaucheria* to a continuous illumination of electric lights for several days and dis-

* The availability and use of various salts by algae in nutritional processes will receive further attention in the chapter on soil algae.

covered to my amazement that the cells were full of starch. Even the yellow-green algae mentioned above may sometimes form starch. It appears likely then that carbohydrates may be formed in all algae, but that in some the further change into fats or proteins takes place almost immediately. If the environmental factors are just right—and we have yet to discover what this means—the sugar changes to starch in most any alga. In other words we may still insist that photosynthesis is necessary before foods are formed in the algae.

In the blue-green algae we discover that the reserves of photosynthesis are glycogen or glycoproteins instead of starch. A carbohydrate reserve of the red algae colors iodine a brown or wine red color instead of blue and is referred to as floridean starch, thought to be a compound intermediate between true starch and dextrin. It should be mentioned that the term applied to this starch is derived from the name of a group of red algae (the Florideae) and not from the appellation of the southeastern extension of the United States into the waters of the Gulf of Mexico and the Atlantic Ocean. White refractive bodies of unknown chemical composition occurring in some algae have been referred to as leucosin; a similar one is volutin; still a third little-known compound is anabaenin. In *Euglena* and its relatives paramylon occurs. We now know very little about these so-called food reserves, but some day we shall know more. And when we do we shall perhaps more clearly see their relation to photosynthesis as it ordinarily occurs in all green plants.

Now that we have found out just what foods are made by the algae, what of it? Well, there are at least two what-of-its that concern a fish, a tadpole, you, and me. In the first place the food of the algae—carbohydrates, fats, and proteins—is just the same kind of food that a fish eats, that a tadpole eats, that you eat, and that I eat. It is also the same kind of food that is made by a giant redwood, by a blade of grass, and by the spinach that makes Popeye exclaim, "I yam what I yam." The children of Mother Nature after all show a great family

resemblance. If you don't believe it try writing out the differences and similarities between plants and animals. You may come to a very unexpected conclusion.

Now this is all very interesting and most people have never thought about it. But the second what-of-it is ever so much more important. When you eat ice cream, bread and milk, beefsteak and gravy, oranges and bananas, why do you do it? Oh yes, I know what you will say: because you are hungry; but I don't mean that. I have in mind, rather, just what do you get out of your food besides appeasing your hunger? What makes you increase in weight? What kind of motor enables you to climb trees, play football, run errands, and fight your enemies?

Suppose we answer these questions by noting what happens to food in the algae.

## CHAPTER III

# HOW ALGAE GROW AND REPRODUCE

IF YOU have been willing to read the previous chapter in its entirety, you have perhaps decided that foods are the most important substances there are, for both plants and animals. Actually that is not true unless something happens to the foods. Did you know that if foods remained foods all living things—and that includes you and me and the algae—would die of starvation? Before the algae can grow and reproduce—and unless growth and reproduction occur in the algae there can be no fishes and pollywogs—the food that has been so elaborately constructed must all be torn down again or be transformed into something else. Let us look into this.

What all takes place when a little boy, an oak seedling, or an alga grows? To answer this question completely would require the services of an expert biologist, physicist, chemist, biophysicist, mathematician, philosopher, and then some more. This is merely another way of saying that nobody knows everything about growth. Scientists have, however, found out a great many things about it, some of which should prove interesting and perhaps entertaining.

Do you know what an algal spore looks like (Fig. 2)? It may be likened, for our purposes here, to a grain of corn. We are again thinking of the algae as grasses, but then we decided not to be disturbed by that. Suppose we examine rather critically a grain of corn: tear off the seed coat (testa), cut the grain open, notice the embryo, look at a small section under the microscope if you want to. Can you see anywhere in that grain of corn such things as green leaves, tassels, pollen, ears, husks, fibrous roots, and several ounces of dry weight? You will doubtless think that is a very, very stupid question. Suppose, however, that you plant the grain of corn in a warm moist soil out-of-doors in summer time. In two or three months

how many of those parts—not visible in the grain—will show up? Where did they come from? When we have answered this question, we shall have learned something about growth.

To get back now to our subject, how may an algal spore

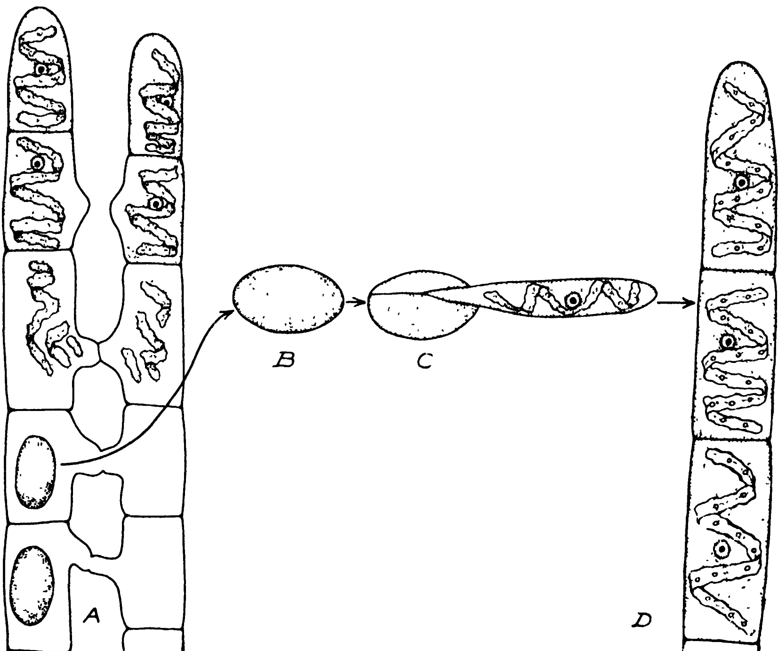



FIG. 2. This is how a spore of *Spirogyra* is formed and this is the way it germinates and grows into a new filament: A, two conjugating filaments; B, ripe zygospore; C, spore germinating into a sporeling; D, new *Spirogyra* plant. Only a few cells of each plant are shown.

grow into an alga? How does a little alga become a big alga?

To be able to grow, an alga (the same is true for you and me) requires energy and building material. Here is where the foods come in. Foods are chemical compounds that both supply energy and may be transformed into cell walls and protoplasm. In the last chapter we learned that foods are classified as carbohydrates, fats, and proteins. The chemical processes involved in changing these foods into cell walls,

protoplasm, and enzymes are included in the term assimilation (Fig. 3).

You may recall that photosynthesis occurs only in the presence of light. To test this out you have but to place a growing green plant in a dark room and see what happens. If the sugar formed in photosynthesis be burned, heat energy is liberated.

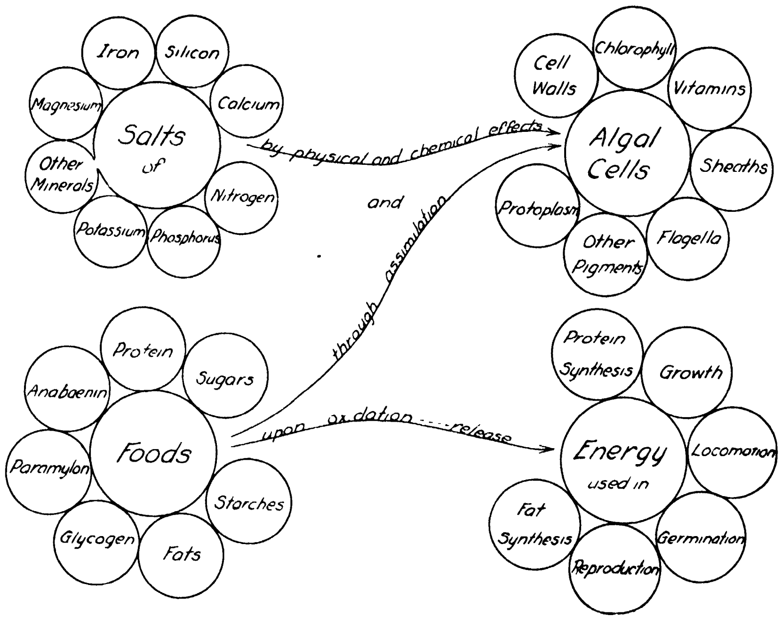



FIG. 3. The foods of the algae must be changed before they are of value to the plants. Our lives are made possible by similar changes in our foods.

The light originally supplied the energy by means of which carbon dioxide and water unite into sugar. When we tear down the sugar—the chemist calls it oxidation while the biologist generally uses the term respiration—this energy is released. Then again when a cell changes from a flaccid to a turgid state, the increase in tension is due to the movement of many trillions of molecules of water into the cell: their movement is a matter of molecular energy. Thus we see that the algae secure energy from three distinct sources; direct light, oxidation of foods, and molecular motion.

Such energy is very difficult for us adequately to visualize or describe. Perhaps it will suffice here if we simply take the conclusions of expert scientists, based on evidence from many experiments, that energy from each of these sources is necessary, directly or indirectly, for the growth of the algae. With this as a starting point, we may now turn to some more particular phases of growth as exhibited by certain kinds of algae.

When a spore of *Spirogyra* grows into a mature plant, there is paraded before our eyes a series of physiological and structural changes that illustrate, even if we cannot follow all the details, the phenomenon of growth. The spore has previously passed through a period of dormancy. It might be merely a few weeks or months or it might be years. Usually the dormant period is during winter months, but it may also occur in drought, in insufficient oxygen, or in other environmental conditions unfavorable to germination; or due to lack of maturity or to other causes dormancy may occur even though the environment is favorable to germination.

Just what goes on in the dormant spore is a matter of considerable uncertainty. The spores of some algae are known to lie dormant for thirty or forty years and then start growing. Is the spore alive all this time? The general belief is that normal physiological processes like respiration, diffusion and perhaps assimilation go on very, very slowly. How else could the spore be living? After all, however, this is merely an assumption. We might, on the other hand, postulate that nothing is taking place in the dormant spore. In your automobile may be gas, carburetor, spark plugs, and a self-starter, but if you don't *step* on the starter, the motor does not move. Nobody would claim that prior to stepping on the starter the motor was slowly—no matter how slowly—turning over. In the spore (or the grain of corn, for that matter) there are foods, gases, water, and enzymes: all the paraphernalia needed for growth. It is an interesting speculation that during this time no physiological processes are in operation; that is, the spore remains dormant until something "starts off" chemical and physical changes. The detonator might be expansion of

water in the cells due to increased temperature, a sudden shift in molecular arrangement, or an added increment of water or oxygen from the outside because of changes in permeability of the spore wall.

Now I know very well just the question that you are going to ask. Is a dormant spore dead, then? If we try to discuss life and death here, we shall get so far away from our subject of algae that we might never be able to return within the compass of a sanely sized little book. What is more important, however, is that we should be little the wiser after such an excursion into what really is metaphysics, theology, some science, and a lot of speculation. We may dispose of the whole question shortly. If a spore or seed will not grow, no matter how long or how much we fondle it or prod it with all our knowledge of what to do to initiate germination, we may call it dead. If it will respond in due time to natural or artificial accelerators, let us say that it is living.

After this digression we can now return to the germination of a *Spirogyra* spore somewhere in the slimy ooze of a pond or lake. The temperature rises, the light intensity increases, and many organisms begin to be active again. The spore wall undergoes chemical and physical alterations that change its permeability, and water and oxygen enter. The spore swells because the water has increased its turgidity, and the wall breaks open. Enzyme action has rendered the insoluble foods soluble. In the meantime the oxygen has united with the sugar and energy has been released. Some of the food is changed into protoplasm and cell wall substances. Mineral salts in solution in the water have diffused into the spore. Simultaneously then there have occurred digestion, respiration, assimilation, diffusion that have resulted in cell enlargement and cell division. Through the break in the wall there emerges a little *Spirogyra* (Fig. 2). The green spirals are soon evident, cross walls appear, and we have in a short time a new plant capable of making its own foods and growing rapidly.

In any pond or lake or stream there are many other kinds of algae besides *Spirogyra*. Do they all grow in the same

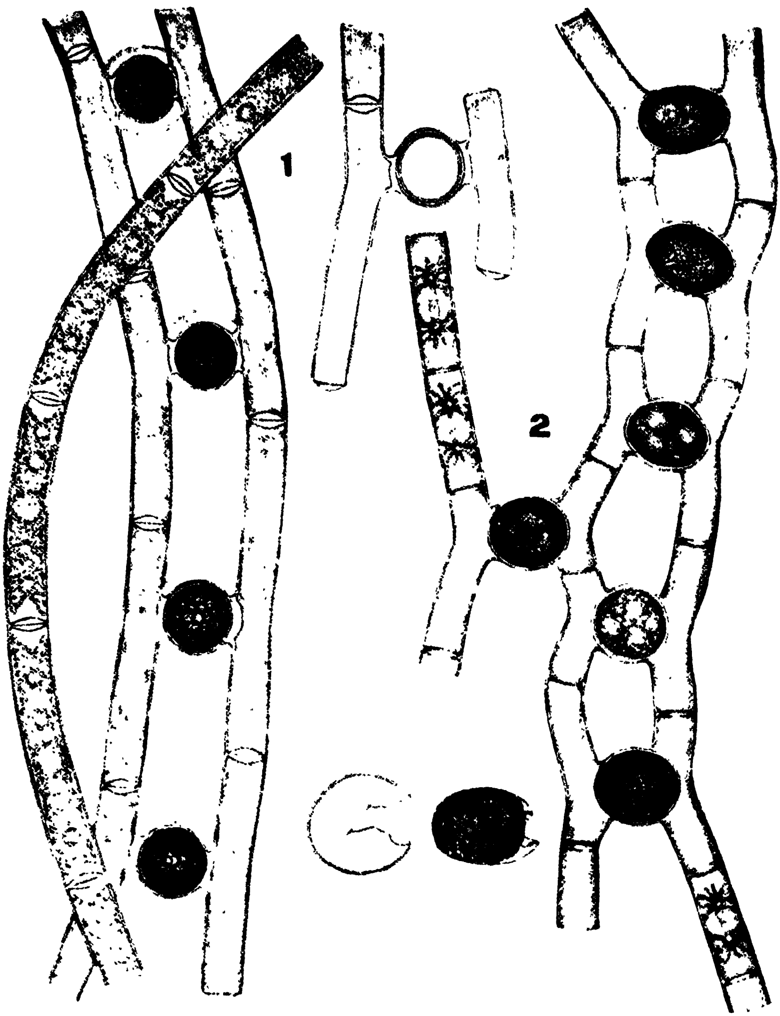



PLATE VI. These two species of the filamentous algae, *Zygnema* and *Mougeotia*, have blue spores that are often ornamented. (After Skuja.)

manner? We have so far thought about growth of algae in general terms: with emphasis upon the part played by food and energy. Suppose that we examine different kinds of algae and see if we can account for their form and appearance. Why are algae branched or unbranched, filamentous or plate-like, solitary or colonial, definitely coenobic or irregularly massed? Every alga inherits from its parent (or parents) potentialities for developing certain patterns of form and shape, from which it does not usually deviate; that is, a filament is ordinarily branched only if its ancestors were branched; or colonial forms are likely to beget only colonial forms. Another way of emphasizing this idea is to say that pattern is pretty largely hereditarily determined. Where the pattern came from originally and why a deviation in its expression may sometimes occur is a difficult matter indeed. To discuss these questions adequately takes us into variations, mutations, and evolution which are scarcely within the scope of this book.

You have noticed that in *Spirogyra* all cross walls occur at right angles to the length of the filament. After the nucleus divides (usually at night) an annular ingrowth from the parent cell wall gradually extends clear across the cell dividing it into two cylinders, one on top the other. The old walls enlarge, and subsequent divisions result in a filament with many septa and many cells. Curiously enough the diameter of the filament fluctuates very little. Most unbranched filaments increase in length precisely as in *Spirogyra*. In *Oedogonium*, however, the septum begins in the middle of the cell and gradually extends outward toward the wall.

If the *Spirogyra* cell formed septa longitudinally as well as diametrically we might have plate-like structures, as in sea lettuce (*Ulva*). If somewhere along the filament there occur lateral outgrowths, which may continue further septation or not, there appears a branched alga, such as the *Cladophora* so common in many streams and along rocky shores of lakes.

Among the unicellular and colonial types there may be solitary individuals if complete separation occurs after cell division; if division occurs in two directions, we have a regular

plate, as *Merismopedia;* if division is in three directions, we have a cubical colony, like *Eucapsis*. Irregular colonies often develop because after division the cells are held in more or less proximity by a common gelatinous matrix. Many algae are incapable of vegetative division and new individuals can be formed only from so-called reproductive cells.

Multiplication in diatoms presents another interesting study in cell division. A diatom cell wall is highly silicified and is composed of two overlapping parts that fit together like the two halves of a pill box. The cells usually undergo division about midnight or in the early morning hours. The cell first increases in size, shortly followed by the division of the nucleus and of the chromatophores. For a short time then there are two protoplasts within the parent cell wall. Each protoplast on its inner side develops a new half-wall, and when mature we have two diatom cells. These two new cells present, however, a very interesting paradox. Each daughter cell is partly parent and partly offspring. That is to say, one half-wall of each new cell is the identical half-wall of the parent; the other is new.

Since the "lid" (epivalve) of the diatom cell fits over the "box" (hypovalve), the former is naturally the larger. Now as a new diatom is formed, the old half-wall becomes in every case the epivalve. What happens as successive divisions of the diatom occur? Evidently there will ensue a gradual diminution in size every time a parent hypovalve becomes a daughter epivalve. This decrease in size is sometimes referred to as Pfitzer's law. It is true, however, that many diatoms possess a certain amount of elasticity, due perhaps to the fact that the silica of the walls is impregnated in pectic compounds. Geitler has observed that an increase in size of cells may sometimes accompany division. Formation of new plants by repeated divisions often proceeds at a very rapid rate. The number of individuals may increase 50- to 100-fold in a week.

The thing that is a bit eerie about diatom cell division is that in a given plant half of its wall may be the identical half-wall of an honorable ancestor many generations removed.

Think of having an eye, an arm, a lung, twelve ribs, and a leg that were used by your great-great-great grandparent (Fig. 4).

So far in our study of growth in algae we have considered only cell division and cell enlargement. We noticed, of course, that very soon after the germination of the zygospore, a *Spirogyra* sporeling develops chloroplasts, chlorophyll, well-

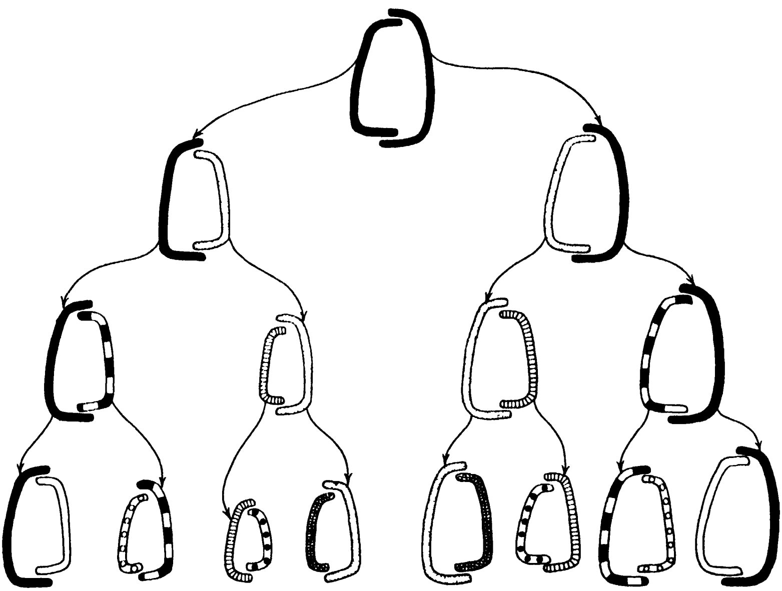


FIG. 4. A diatom and its progeny for the next three generations. Note that two "great-grandchildren" have each an identical valve belonging to the great-grandparent. These two halves might be used almost indefinitely. It is also seen that some plants of each succeeding generation become smaller. Why is that?

defined nucleus, and cytoplasm. Differentiation of cells in the algae is not as evident in vegetative growth as it is in seed plants, like corn, where definite organs are present. We do have, however, numerous examples of cell differentiation in the algae, even before the initiation of spore production. In addition to the ordinary cells of the filaments there may be holdfast cells, setiferous cells, rhizoidal cells, apical cells, and peripheral cells.

The spores of many algae show a definite polarity upon germination. The akinete of *Pithophora*, for example, develops a holdfast cell at one end only. The opposite pole by repeated division after germination produces the remainder of the plant. Curiously enough, when these akinetes are exposed to continuous artificial illumination at summer temperatures, growth takes place in four directions—from opposite ends of two axes instead of one axis—and no holdfast cell is formed.

Perhaps the greatest differentiation found among the algae occurs in such marine brown algae as the giant kelps (*Laminaria* and *Macrocystis*), the sea otter's cabbage (*Nereocystis*), and the sea palm (*Postelsia*). In these plants there are large holdfast structures that superficially resemble roots, stem-like stipes with pseudo-conducting systems, and expanded leaf-like blades that may reach a hundred feet in length. In many of the red algae the larger branches consist of several rows of elongated cells of which the outer rows are differentiated from the inner ones. The peripheral division is sometimes referred to as cortical, because of its apparent similarity to the cortex of seed plants.

To pursue the subject of differentiation further, we may study the formation of reproductive structures in algae. The protoplasm of a vegetative cell may form a new wall within the old wall and go into a state of dormancy: such a cell becomes an aplanospore. If the vegetative cell wall is merely thickened, the resultant dormant resting cell is an akinete. Such cells may remain inactive for considerable periods of time before resumption of growth. Again, the contents of a cell may become active, round up, and burst through the wall. This kind of protoplast develops whip-like projections—either 1, 2, 3, 4, or many—known as cilia, and it is capable of independent locomotion. After swimming around for a few minutes to a few hours, this zoospore (that is, an "animal" spore, because it moves) absorbs the cilia, becomes quiescent, and begins almost immediately to grow into a new plant like the parent. Often growth begins while the zoospore is still in motion. For some time such an active spore was thought

to be an animal, although the green color was very disturbing (Fig. 5). Now we know that locomotion or the lack of it is not necessarily a criterion of distinction between plants and animals.

Sometimes a ciliated protoplast unites with another proto-

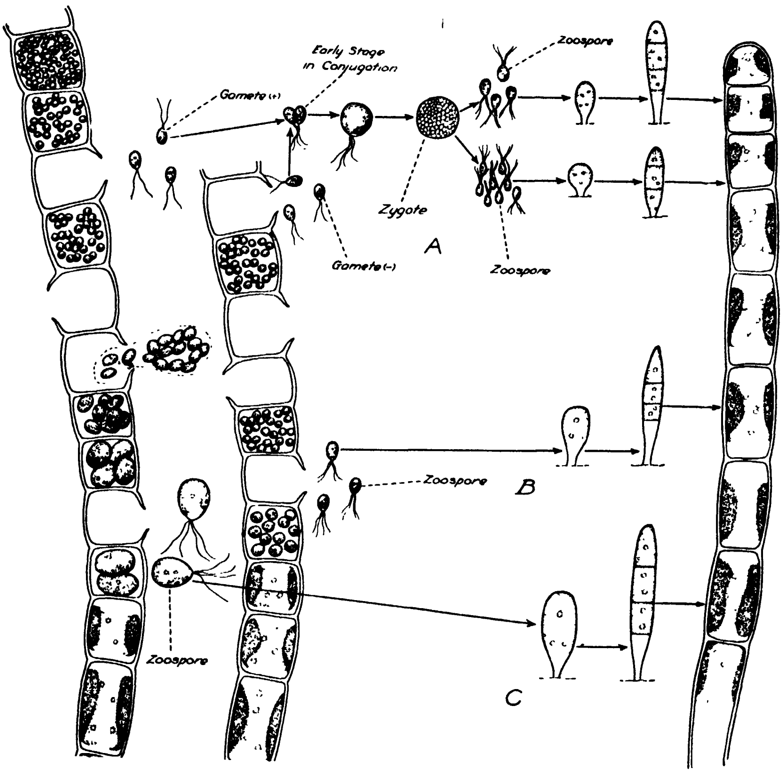



FIG. 5. Reproduction in the algae takes place in many ways and many structures may be involved: A, sexual reproduction; B, C, two forms of asexual propagation, in *Ulothrix*.

plast, forming a new type of spore, the zygospore or oospore. Such a ciliated protoplast is known as a gamete. The gametes may be superficially similar, but if so they have usually developed from different plants, or at least from different cells of the plant. They are referred to as plus and minus gametes. Sometimes they look just alike except for size. In other cases

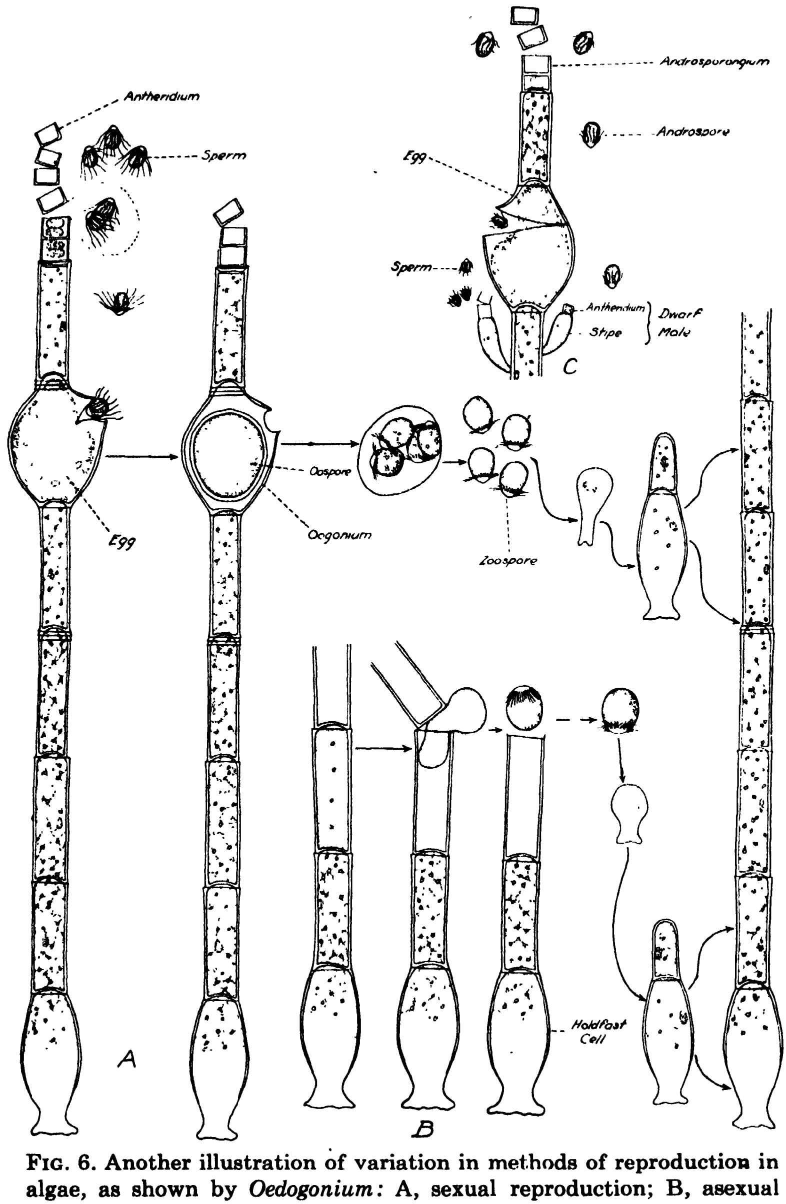



FIG. 6. Another illustration of variation in methods of reproduction in algae, as shown by *Oedogonium:* A, sexual reproduction; B, asexual propagation; C, sexual reproduction peculiar to *Oedogonium* and its related genera, *Bulbochaete* and *Oedocladium.*

the two gametes are quite dissimilar. One is small, with little food reserve, and capable of locomotion—the sperm. The other—the egg—is much larger, contains lots of stored food, and is stationary. In such cases due to some causal attraction not clearly understood, the sperm finds the egg and fertilization may then occur (Fig. 6). It has been found by Spessard that in *Oedogonium* the formation of sperms and subsequent fertilization have a maximum development between midnight and four A.M. A second lesser culmination occurs in the early hours of the afternoon. During the time of reproduction small numbers of sperms may be discharged at any hour of the day. A sperm that does not fertilize an egg ceases movement within two hours and is completely disintegrated in from six to thirteen hours.

The actual fertilization of an egg by a sperm in *Oedogonium* has been studied by Spessard in detail. The entire time elapsing between the discharge of a sperm and its passage into an egg may be only two minutes. About a half-minute is required to reach the opening of the egg-case (oogonium). Another thirty seconds is consumed in the actual passage of the sperm into the egg. A sperm is not likely to enter an oogonium if fertilization has already occurred. If two sperms are found inside the egg-case, only one unites with the egg. The forces which cause the sperm to pass into the egg by a sort of gliding movement are not understood. The rate of gliding is quite slow, perhaps 1 to 2 millimeters in an hour. The actual fusion of the nuclei of sperm and egg, together with subsequent development of a thick-walled oospore, often highly ornamented, requires several days.

It is not an uncommon phenomenon in the algae for an egg to grow into a spore without fertilization by the sperm. Such a spore in thus giving rise to a new plant upon germination is a case of parthenogenesis (virgin birth). Crosses between different species of algae, resulting in hybrids, have been observed, but little is known of the progeny of such hybrids.

Some *Oedogoniums* and their close relatives furnish another peculiarity exhibited by algae developing sperms and eggs

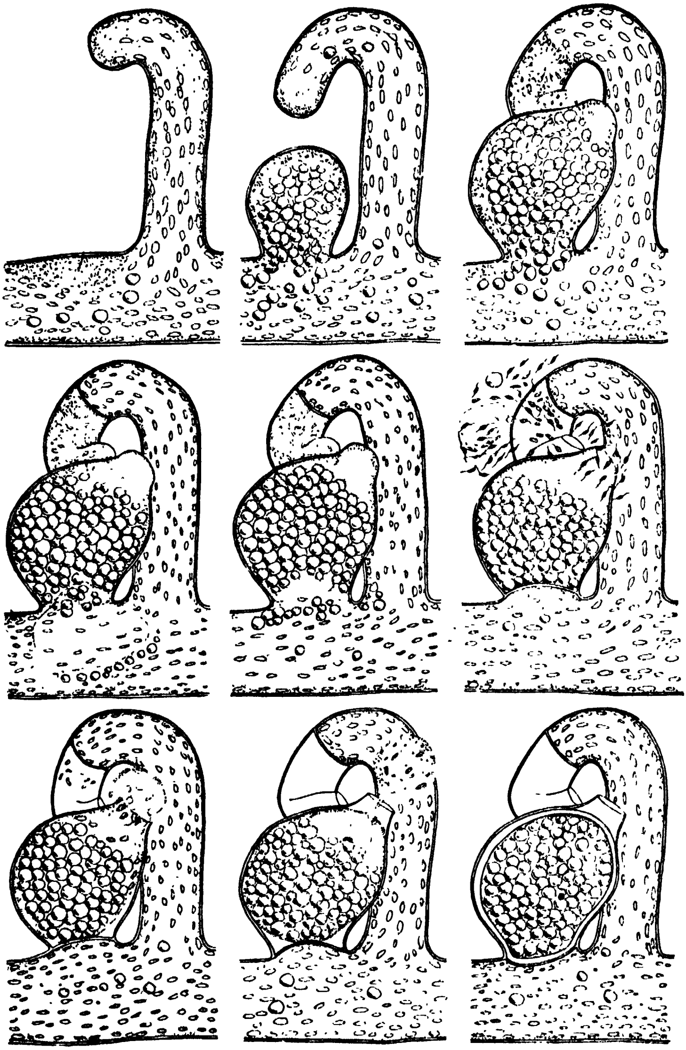


FIG. 7. Sexual reproduction in the oil-forming *Vaucheria*. (From Couch, *Botanical Gazette*, published by The University of Chicago Press.)

(Fig. 6). A ciliated protoplast which is apparently identical to a sperm emerges from a cell, swims around for a time, and then comes to rest *near* the egg, never uniting with it. Instead it grows into a little plant ("dwarf male") which in turn produces real sperms. The intermediate or nearly neutral protoplast which gives rise to the dwarf male and hence the sperms is termed an androspore.

*Spirogyra* and its family kin exhibit one of the most curious forms of reproduction known. No ciliated protoplasts are ever formed. Two threads lying close to each other develop protuberances, one from a cell, somewhat as if a branch were to be formed. The ends of the two protuberances meet, the points of contact dissolve, and a hollow tube results connecting two cells from adjoining filaments. When many of these tubes occur at one time between adjacent plants, a ladder-like structure is formed with each tube serving as a rung: this is known as scalariform conjugation (Fig. 2). In other cases the tube may be formed between adjacent cells of the same thread: lateral conjugation. The protoplast of the male cell disintegrates and moves through the tube into the protoplast of the female cell. In order to observe this gametic union it is usually necessary to examine the algae sometime between midnight and dawn. The union of the gametes results in a zygospore. In some plants closely related to *Spirogyra* the two gametes meet in the middle of the tube, and a zygospore is formed there. In certain other algae kneeing of the filaments takes place and conjugation occurs without a regular tube.

A somewhat similar type of conjugation occurs also among the diatoms, although the variations are perhaps even more pronounced than in *Spirogyra*. The two diatom parents may produce two gametes (one each), similar in size or not, which upon union form a zygospore that the diatomists term an auxospore. In other cases the parents produce four gametes (two each), and upon conjugation two auxospores are formed: perhaps these are the original diatom twins. In a few diatoms just one parent seems all that is necessary; that is, the single protoplast forms two gametes (or sometimes just two nuclei)

which fuse and grow into an auxospore. Apparently similar auxospores occur in some genera of diatoms by simple vegetative growth.

We have already discussed the germination of the spores of algae, and so have completed the cycle: from spore to spore, or from vegetative cell to vegetative cell. Reproduction in the red and brown algae is considerably more complex in many respects than we have just described, and we shall briefly refer to it in a later chapter.

## Chapter IV

# ALGAE OF LAKES AND PONDS

In the preface of this book allusion was made to the intriguing impossibility of knowing the world as seen by fishes and frogs and pollywogs. These creatures—and many others—of lakes and ponds live in an aqueous cosmos which we can interpret only in terms of our limited human experiences. Certain things are, however, observable facts. Light penetrates the water, and through chlorophyll a series of chemical processes is initiated in the algae that results in food for both plants and animals.

Living creatures as numerous as the sands of the sea use food, grow, multiply, reproduce, and die—endlessly, eternally adding to the organic compounds of lake bottoms. The race is largely to the swift, to the strong, to the crafty. Such is the case for the animal forms, and even the plants must undergo competition for oxygen, carbon dioxide, light, mineral salts, and space. From such a viewpoint Nature is not very lovely: survival value is all that counts in the long run. In such a stupendous struggle for existence on so microgigantic a scale in ponds and lakes the world over, there must be many interesting facts of life for us supposedly sophisticated members of the twentieth century who have seen everything, heard everything, and even smelled everything. Let us see.

Like the little boy who asked his mother, "How much is six?" we might inquire, "How much is a lake and how much is a pond?" The answer to the one is about as enlightening as the answer to the other. The usual method is to consider the small bodies of water ponds and the large ones lakes. As a matter of fact no sharp physical distinction between the two can be made. Perhaps the best basis for separation rests on depth of water rather than on actual area. Ponds may be considered to be without thermal stratification, and that

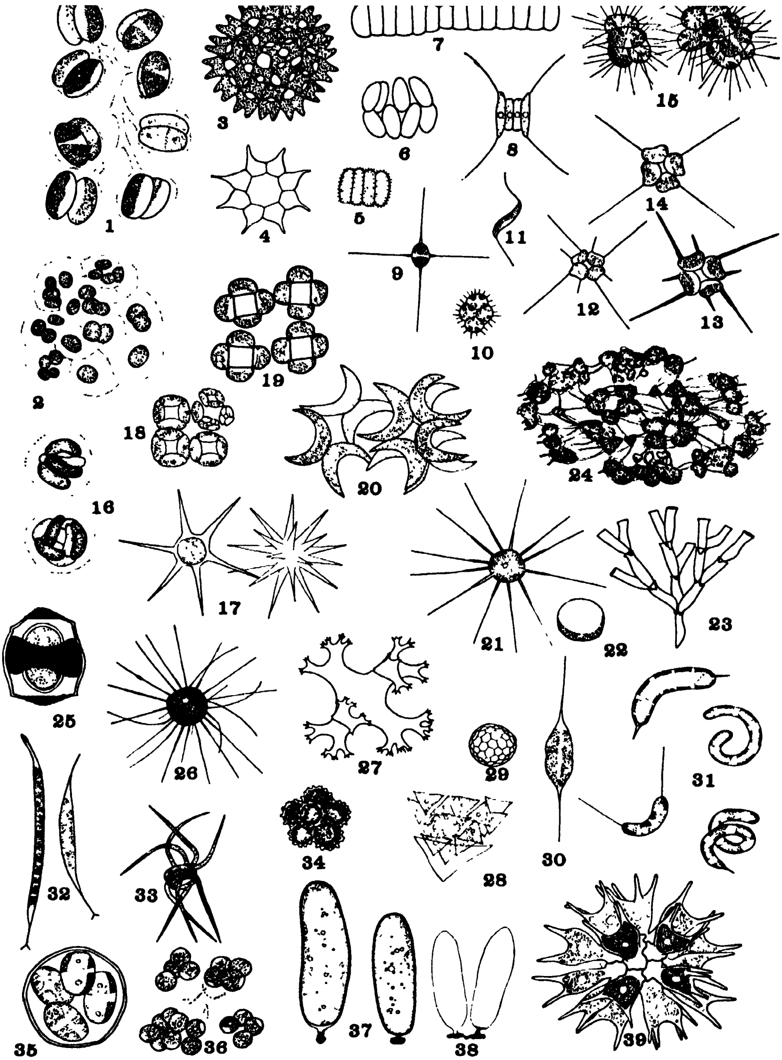



PLATE VII. Many plankton algae have no means of locomotion in the vegetative state. Movement of such algae is dependent largely upon outside influences: 1, *Dictyosphaerium;* 2, *Gloeocystis;* 3, 4, *Pediastrum;* 5–8, *Scenedesmus;* 9, *Lagerheimia;* 10, *Tetrastrum;* 11, *Schroederia;* 12–14, *Tetrastrum;* 15, *Franceia;* 16, *Nephrocytium;* 17, *Echinosphaerella;* 18, 19, *Crucigenia;* 20, *Selenastrum;* 21, *Acanthosphaera;* 22, *Chlorella;* 23, *Dinobryon;* 24, *Botryococcus;* 25, *Gloeotaenium;* 26, *Golenkinia;* 27, 28, *Tetraedron;* 29, *Trochiscia;* 30, *Centritractus;* 31, *Ophiocytium;* 32, *Characium;* 33, *Ankistrodesmus;* 34, *Coelastrum;* 35, *Oocystis;* 36, *Westella;* 37, 38, *Characiopsis;* 39, *Sorastrum.* (2, after Cienkowsky; 3, 5–10, 12–14, 16–19, 21, 27, 35, 39, from Tiffany, after G. M. Smith; 34, from Skuja; 37–38, from Cedercreutz.)

includes depths up to fifteen feet or more. Lakes deeper than 50 feet have constant thermal stratification. Rooted vegetation may occur nearly anywhere in a pond, but not in a lake. If the latter difference be adhered to strictly, shallow-shored areas and protected inlets of lakes are ponds or semi-ponds.

Even if demarcation between the two cannot be definitely established there are some real differences. Ponds usually have better-lighted bottoms, warm up more quickly, are less subject to the churning effects of winds, and in proportion to volume of water have a greater abundance of algae. Lakes on the other hand remain warm longer in the autumn, may have areas too dark to support vegetation, have definite thermal stratification, and are subject to violent agitation by the wind. Ponds may be permanent or temporary, the latter contingency introducing extremes of water supply that may profoundly affect both plant and animal life. Suppose as a matter of convenience that we discuss environmental factors in relation to algal growth in lakes and indicate as we proceed wherein pond conditions differ.

Perhaps the most striking phenomenon occurring in lakes is the appearance during late summer of so-called "water blooms." These blooms have been accounted for by the layman as masses of pollen from nearby conifers, purification processes, fermentations, "dog days," or even manifestations of evil in the water. They are in all cases, as you have already suspected, made up of algae, and the algae concerned are often blue-greens. The water in a day or so may become turbid and appear green or greenish-yellow, depending upon the kind of algae present. The "bloom" often becomes as thick as pea soup. Such an algal harvest may persist for some weeks or it may disappear in a few days.

The free-floating algae comprising the bloom is known as the phytoplankton, or more often just plankton, although the latter term may include animal forms (zooplankton) as well. It must be understood, however, that extremely clear lakes, or any lakes for that matter, have their own plankton flora even if blooms never develop. The supposedly poisonous effects of water blooms will be discussed in a later chapter.

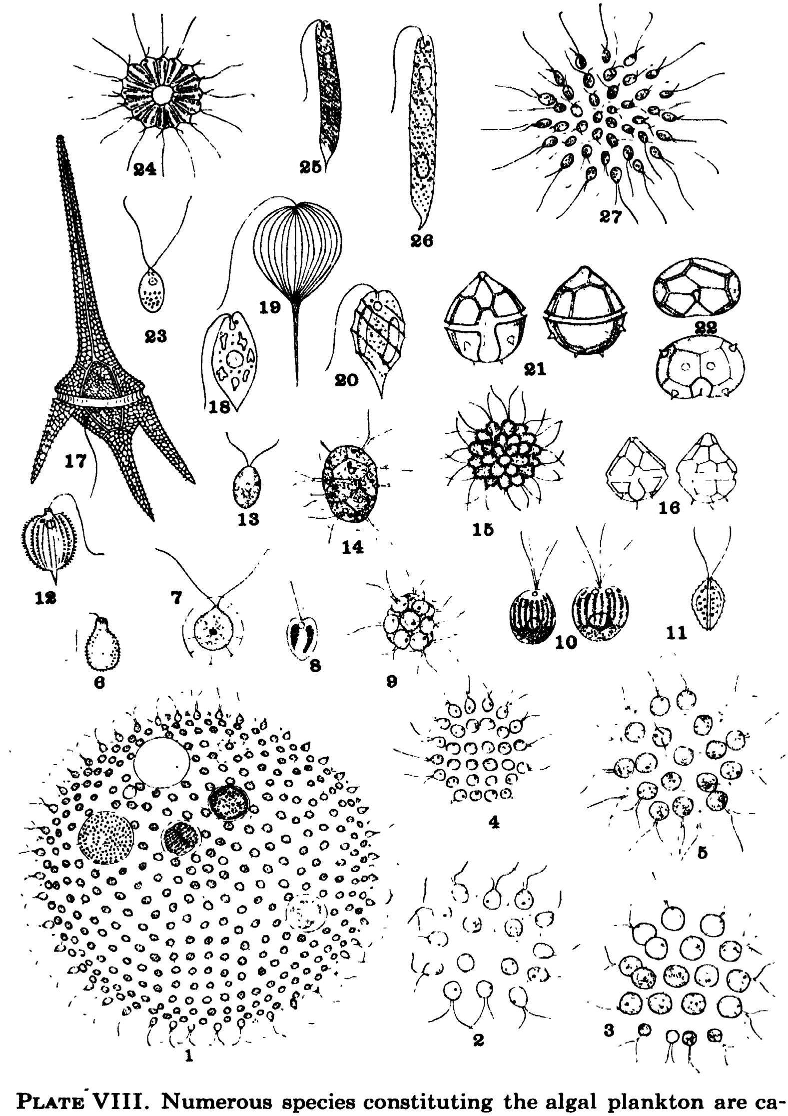



PLATE VIII. Numerous species constituting the algal plankton are capable of locomotion, due to the presence of flagella or cilia: 1, *Volvox;* 2, *Gonium;* 3, *Pleodorina;* 4, *Platydorina;* 5, *Eudorina;* 6, *Trachelomonas;* 7, *Sphaerella;* 8, *Ochromonas;* 9, *Pandorina;* 10, *Carteria;* 11, *Phacotus;* 12, *Phacus;* 13, *Chlamydomonas;* 14, *Pandorina;* 15, *Synura;* 16, *Peridinium;* 17, *Ceratium;* 18, *Euglena;* 19, 20, *Phacus;* 21, 22, *Peridinium;* 23, *Polytoma;* 24, *Cyclonexis;* 25, 26, *Euglena;* 27, *Uroglenopsis.* (2, 3, 27, after G. M. Smith; 8, after Pascher; 16, after Eddy; 18, after Haase; 20, after Lemmermann; 21, 22, after Griffiths; 25, 26, after Walton.)

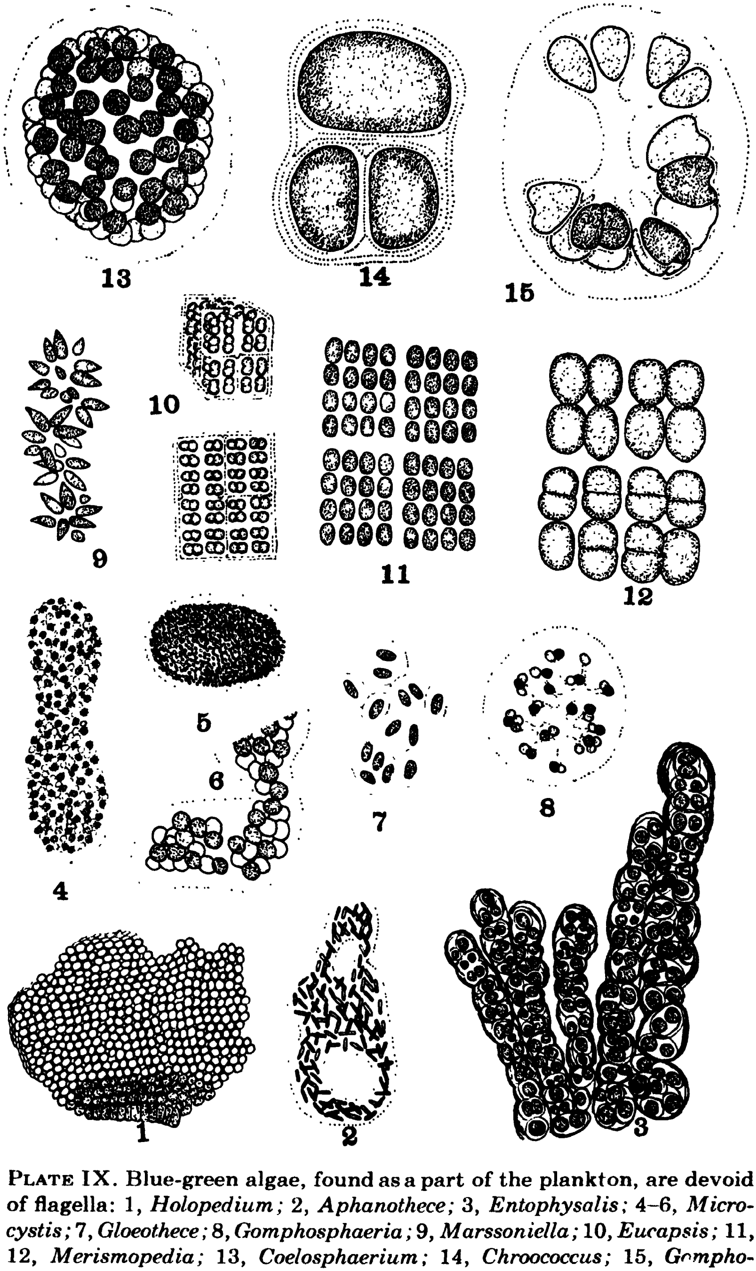



PLATE IX. Blue-green algae, found as a part of the plankton, are devoid of flagella: 1, *Holopedium;* 2, *Aphanothece;* 3, *Entophysalis;* 4–6, *Microcystis;* 7, *Gloeothece;* 8, *Gomphosphaeria;* 9, *Marssoniella;* 10, *Eucapsis;* 11, 12, *Merismopedia;* 13, *Coelosphaerium;* 14, *Chroococcus;* 15, *Gomphosphaeria.* (3, from Frémy; 8, 12, 13, 15, from Tiffany, after G. M. Smith; 10, after Clements and Shantz.)

Some algologists have attempted to classify plankton on the basis of the bodies of water in which the algae grow. The plankton of lakes is known as limnoplankton, that of ponds as heleoplankton, and that of rivers potamoplankton. Of the limnoplankton the shore forms, both attached and free-floating, comprise the benthos; the so-called "true plankton," or pelagic forms, is found in mid-lake and does not have its origin in shallow margins. A good many plankton forms are both benthic and pelagic, and G. M. Smith has suggested the term facultative planktons for them. The distinction between a heleoplanktonic and a limnoplanktonic flora is in some regions quite marked and in others not noticeable.

We have seen previously that the prime requisites (other than water) for the growth of algae—and for that matter any green plant—are light, suitable temperature, carbon dioxide, oxygen, and certain mineral salts. During the last half century an impressive array of experimental and observational data has been accumulating regarding the influence of environmental factors upon the growth of algae. Suppose we examine light first.

Light is another of those every-day phenomena which nearly everybody recognizes but which few know much about. We have learned that the green pigment of plants rarely develops in darkness and that growth of plants is generally retarded in bright light. The average person is well aware that when there is light he can see and when there is no light he cannot see, that the taking of pictures is somehow related to light, and that exposure to the summer sun inevitably means sunburn, and lets it go at that. Most of us, though, are fairly familiar with such terms as visible light, ultraviolet, infrared, x-rays, and radio waves, even if our definitions of them would likely paralyze a physicist.

The light we are all most familiar with perhaps is the radiation constituting the visible spectrum. Certain emanations from a luminous body like the sun travel some 186,000 miles per second. When these rays strike our retina we may perceive colors, although of course sunlight itself produces no

color impression to our eyes. The colors we ascribe to an object depend upon the kinds of rays of light passing from the object to our eyes. If an object reflects no light, it is said to be black; if all rays of the spectrum are reflected in equal degree, the object is white; if the object absorbs some rays and reflects others, it is the wave lengths of the reflected light which the eye interprets as color. Really then what color is a red apple?

The familiar bands of color in the rainbow are the result of refraction and reflection and other changes in the sun's rays as they pass through drops of water. The red at one end is due to long waves and the violet at the other end is due to short waves of light. The orange, yellow, green, blue, and indigo are the result of waves of intermediate length. And so we have a visible range of color from the red at one end to the violet at the other. Now these light waves have fairly definite wavelengths and we may separate them on such a basis. The visible spectrum is the radiant energy of wave lengths between about 3900 and 7800 angstrom units.*

But of course the visible light is by no means all there is to it. The long rays of the infrared may range from 7800 to over a million Å. As a matter of fact if we continue in the "long end" of the spectrum we reach radio waves that may be several miles in length. At the other end of the scale the ultraviolet has a range from about 100 to 3900 Å and beyond that the so-called cosmic ray may have a length scarcely a thousandth of an angstrom unit. Light is held to be an electromagnetic phenomenon and we may properly speak of the electromagnetic spectrum. (See Table 2.)

The ultraviolet light important in sunburn and tanning and perhaps to growth in general lies between 3000 and 3900 Å. The infrared region that is quite likely also important in growth extends a short distance beyond the red limit of the visible spectrum. The yellowish-green, green, and bluish-green regions of the spectrum have been shown in some cases to be

* An angstrom unit (Å) is equal to one ten-thousandth of a micron, and you ought to know what a micron is.

TABLE 2. APPROXIMATE WAVE-LENGTHS OF THE ELECTROMAGNETIC SPECTRUM

| Spectrum | Wave lengths | | |
|---|---|---|---|
| | Angstrom Units | Microns | Millimeters |
| Cosmic Rays | ? to .001 | ? to .0000001 | ? to .0000000001 |
| Gamma Rays | .001 to .1 | .0000001 to .00001 | .0000000001 to .00000001 |
| X-Rays | .1 to 100 | .00001 to .01 | .00000001 to .00001 |
| Ultraviolet | 100 to 3900 | .01 to .39 | .00001 to .00039 |
| Violet | 3900 to 4300 | .39 to .43 | .00039 to .00043 |
| Blue | 4300 to 4700 | .43 to .47 | .00043 to .00047 |
| Blue-green | 4700 to 5000 | .47 to .50 | .00047 to .00050 |
| Green | 5000 to 5600 | .50 to .56 | .00050 to .00056 |
| Yellow | 5600 to 6000 | .56 to .60 | .00056 to .00060 |
| Orange | 6000 to 6500 | .60 to .65 | .00060 to .00065 |
| Red | 6500 to 7800 | .65 to .78 | .00065 to .00078 |
| Infrared | 7800 to 1000000 | .78 to 100 | .00078 to .1 |
| Radio Waves | 100000000 to ? | 10000 to ? | 10 to ? |

important in chlorophyll formation, while much of the ultraviolet and infrared portions may be inimical to its synthesis. Perhaps most of the visible spectrum is effective in chlorophyll formation if the energy value is ample. The amount of greening in any wave length differs in strong and weak light. In general, if energy values are about the same, the red rays are more effective than the green, and the green more valuable than the blue.

It is quite incautious perhaps to make generalizations regarding the influence of different rays of light upon plants. Reliable research into the biological effects of solar radiation is just in its infancy. It is, however, a fascinating field of investigation, and we shall doubtless make rapid progress in the next decade or so. Dr. Meier of the Smithsonian Institution, for example, secures some interesting data from a study of the effects of various wave-lengths of light on the green alga, *Stichococcus*, under known light intensity. In two weeks the algae in full daylight had quadrupled in quantity; they increased over three-fold in the blue region; they doubled in the yellow and red; they decreased in cell numbers in the green; and in the infrared there was no change, or the algae were similar to those grown in darkness. The color of the plastids was the usual green in the blue, red, and yellow rays as well as in daylight; plastids were green but full of granular material in the green and infrared; and as to be expected, colorless or at best yellow-green in darkness.

The amount of light absorbed varies in different lakes. Those with clear water absorb the least. In colored water, moreover, absorption of red rays is less than that of the blue rays; in clear water the reverse is true. Blue rays are scattered by suspended particles more than red rays, and so light passing through turbid water has a lower percentage of blue than light passing through clear water. Both color and seston are more obstructive to the short waves than to the long ones. The amount of light obtained just at the surface of the water is by no means the same as that secured by the algae at different depths. The amount actually received by the algae— not

the total radiation at the surface—is of course the item of most importance to plants. Clark and Oster observed that the depth at which photosynthesis just balances respiration for certain plankton algae was seven to twenty meters in turbid water and about thirty meters in clear water.

Birge and Juday have estimated that the photosynthetic zone in clearwater lakes is the upper ten meters; in more turbid or colored water it may be less than two meters. To put it in a slightly different way: in the upper foot-zone the algae below the surface are practically equally illuminated on clear days. At greater depths the percentage of transmitted light decreases rapidly until at ten to fifteen meters the amount is usually less than one percent of that in the upper few inches. Radiation of wave-lengths greater than 5600 Å (yellow, orange, red) is rapidly absorbed as light penetrates the water.

There are various instruments and devices for measuring the amount of radiation delivered at various depths of water, but most of them are too complex for a profitable discussion here. Essentially the more accurate ones either (1) measure the potential produced when light falls on a thermopile, by a milli-voltmeter or by a galvanometer; (2) determine subaqueous intensities in relation to full daylight by estimating the amount of iodine liberated when a solution of sulphuric acid and potassium iodide is exposed to the two intensities; or (3) include the principle of the photoelectric cell. A method for securing comparative values is by lowering a white disc—the well-known Secchi's disc—and recording at what depths it disappears from view.

For all practical purposes we may say that the growth of algae is very closely correlated with their photosynthetic activity. From what we already know about light and its penetration into water, it is not difficult to see why most algae are found in the upper few inches of lake water. Algae of course can exist under certain conditions of very low light intensity and considerably below depths of ten meters. Species of *Cladophora*, *Gomphonema* and *Gongrosira*, for example,

have been collected in Lake Constance at depths of 30 meters.

This profundal community of algae has a limited oxygen supply and must therefore carry on respiration at a minimal rate. The low light intensity certainly does not allow for much photosynthesis. The algal forms are furthermore deeply pigmented, reddish to reddish-brown predominating over the green. It is interesting to note that such plants of the deep represent six great classes of algae: diatoms, blue-greens, freshwater reds, freshwater browns, Cryptophyceae, and greens.

It must not be assumed however that, because light is so necessary for algal growth, the greater the intensity the better the growth. Just the reverse may be true, within limits. In fact algologists very early learned that in the northern hemisphere north windows are much more suitable than south windows for exposing laboratory cultures of algae to light. Very bright light is destructive to most algae in such cultures. Perhaps this is one reason why in lakes fewer algae occur right at the water surface than just below it.

We have so far omitted mention of the effects upon algae of other plants in the water or along the shore. Competition of flowering plants with the algae is not an important factor in lakes, except in their shallower areas, but is of considerable significance in ponds. Trees, shrubs, and large herbaceous plants may fringe the pond and prohibit growth of algae near the shore by too much shade. Floating leaves of water lilies, pondweeds, and smartweeds, as well as the flattened stems of duckweeds, may completely cover good-sized ponds to the practically complete elimination of most algae.

The importance of temperature in aquatic habitats has perhaps been over-emphasized rather than the reverse. During winter months many algae lie dormant either in the vegetative state or as spores, and growth does not normally occur until the rising temperatures of early spring. It is surprising, however, how many different kinds of algae may be secured in winter even under the ice. The relatively large individuals of *Oedogonium*, *Cladophora*, *Spirogyra*, and *Vaucheria* may be collected most any time in temperate zones during the year.

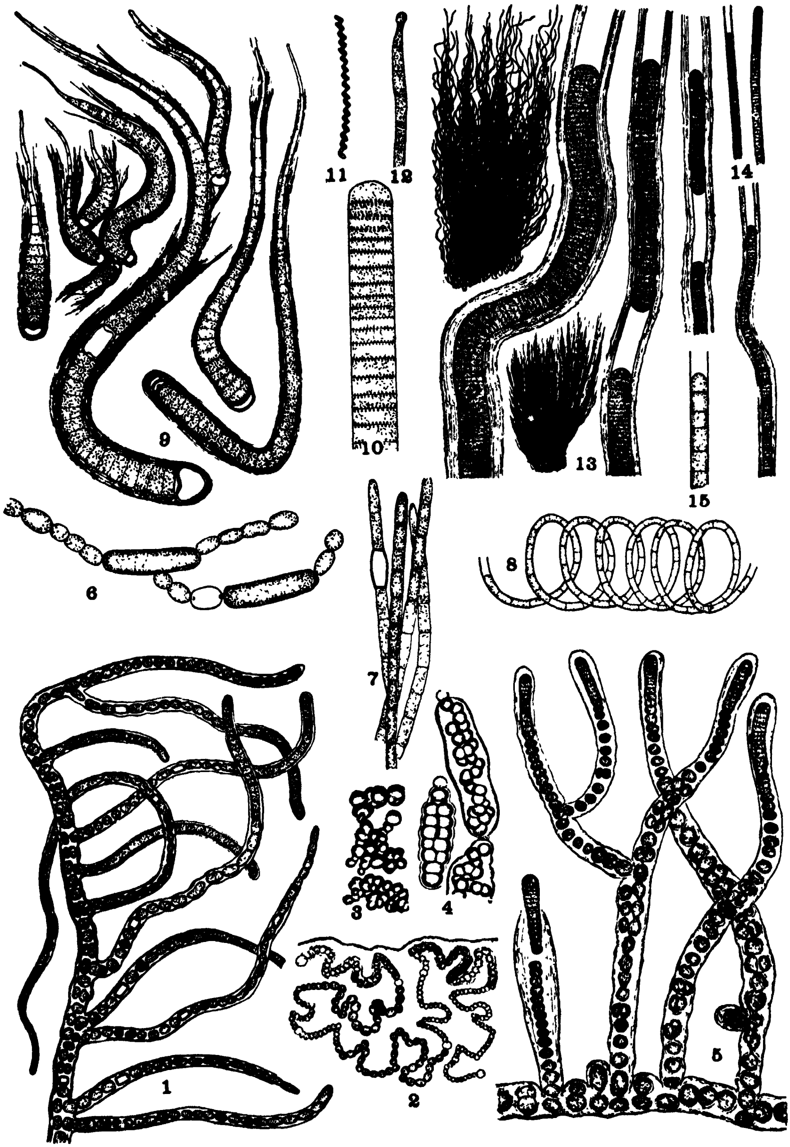



PLATE X. The larger filamentous blue-greens may be a part of the plankton, or they may be attached to various substrata. Some of these forms are: 1, *Hapalosiphon;* 2–4, *Nostoc;* 5, *Stigonema;* 6, *Anabaena;* 7, *Aphanizomenon;* 8, *Lyngbya;* 9, *Calothrix;* 10, *Oscillatoria;* 11, *Spirulina;* 12, *Oscillatoria;* 13, 14, *Lyngbya;* 15, *Phormidium.* (1–5, 9, 13, 14, from Frémy; 6, after Tilden; 8, 11, from Tiffany, after G. M. Smith; 15, after Gomont.)

Many diatoms are very abundant in winter, and certain ones reach their maximal development in that season. In such cases, however, temperature may be only a secondary factor to the influence of precipitation on the supply of mineral salts.

It is impossible to state what range of temperature is best for the growth of algae, because it is different for different species. In arctic and antarctic regions there are so-called snow floras of algae (the Cryoalgae) that pass their entire existence on the ice and snow. Even in temperate regions algae in a vegetative state may be frozen for months and then resume growth upon the melting of the ice. Red blooms of plankton in some Swiss lakes may occur only at near-freezing temperatures. On the other extreme, some species of algae are reported from hot springs at temperatures as high as 94° C, but this observation made some seventy years ago is doubtless about 10° too high.

It is difficult to see how algae can survive at such high temperatures. Protoplasm in the algae apparently remains a living system at temperature ranges (roughly) from freezing to boiling. No protoplasm has so far evolved that can survive for long at temperatures beyond either extreme. Perhaps an average range for optimum growth of algae—keeping in mind that other factors may appreciably alter it—is from 10 to 20° C.

The periodicity or seasonal growth of algae is often attributed to effects of temperature, but it is very doubtful if such influences can be entirely divorced from those of light and certain mineral salts. Diatoms and many blue-greens reach their maximal growth in Lake Erie (Ohio) in late summer and autumn. A lesser culmination may occur in June-July. The green algae may have periods of paramount growth in late spring or early summer. Periods of maximum growth of algae in ponds do not quite correspond to those in lakes, chiefly due to the difference in time required to warm and cool the water at the equinoxes; that is, spring and autumn climaxes in ponds are reached earlier in the year. Geographical

location, of course, alters the actual calendar time of greatest growth, but the seasons are comparable.

The spring and fall maxima are to be explained largely on the influence of the "turn-over" of the water at these two seasons. The deeper water (hypolimnion) of lakes has no circulation and therefore no change of temperature from approximately 4° C during the year. The upper layers (epilimnion) are subject to practically complete turbination of water in the fall and in the spring, due to differences in density of the water at different depths as air temperature changes. The region of transition (the thermocline) is usually quite sharp. The "turn-over" of the water insures a more equable distribution, for the time being, of carbon dioxide, oxygen, and mineral salts necessary to the synthetic, respiratory, and assimilatory processes in the algae.

Autumn and spring "turn-overs" are fundamentally attributed to a peculiar property of water: it is most dense at 4° C and not at freezing. In the autumn, lowering air temperatures decrease the temperature of the upper layer of water and increase its density. The relatively warmer and lighter layers of water immediately below the surface are replaced by the cooler, heavier surface water. This interchange of temperature levels continues until the water is uniformly about 4° C. Subsequent lowering of the air temperature may of course cause the formation of ice, but it is lighter than the water immediately below and so remains at the surface. If water reached its greatest density at zero, lakes would become solid cakes of ice in the winter, and summer melting would be superficial and comparatively trivial.

As spring approaches with its warmer air temperatures, the ice melts and the resulting surface water rises in temperature. This upper layer of water soon becomes near 4° C and thus is now warmer and heavier. It gradually replaces the lighter water immediately below. This mixing, often aided by wind, continues until the whole lake is of about the same temperature and density. As higher air temperatures appear, the upper layers of water may become considerably warmer

and lighter, but they remain in place unless stirred by the wind or other agencies, until the coming of autumn. Because no turn-overs of this kind occur in winter or summer, these seasons are often regarded as stagnation periods of the lake. In the summer the warmer water is at the surface while in winter the colder water (or ice) is on top; in either case the surface water is lighter.

Seasonal successions of algae in a lake are comparable to the familiar changes in the vegetational aspects of country-sides throughout the year. The vernal landscape of spring beauty, wild ginger, violet, and crowfoot is in considerable contrast, for example, to aster, sunflower, white top, and golden rod of late summer and early autumn. Similar situations are illustrated by the spring and autumn preponderance of diatoms; the early summer productivity of greens; the late summer and early fall maxima of blue-greens; and a culmination of some diatoms even in winter.

Certain seed plants come into bloom in spring, others in summer, and still others in autumn in north temperate latitudes. Very similar development occurs among the algae. On the basis of time of maximal sexual activity, Transeau has classified algae into winter, spring, summer, and autumn annuals (Fig. 8). Even the species that vegetate perennially have quite definite seasons of spore production.

It was suggested above that the supply of carbon dioxide and of oxygen was important to the growth of algae. What data are known regarding the availability of these raw materials?

On the basis of oxygen supply lakes are sometimes divided into three groups. (1) The oligotrophic lake is one in which there is a goodly supply of dissolved oxygen at all depths during the stagnation periods of summer and winter. (2) The eutrophic lake has a paucity of dissolved oxygen in the lower strata in late summer. The decomposition of large quantities of organic matter present uses up the oxygen supply. (3) The dystrophic type of lake, apparently common in Europe, has brown colored water due to vegetative substances from peat

bogs and marshes. The third class of lake is perhaps unimportant as a distinct type in the United States. Birge and Juday examined some 500 lakes in Wisconsin and found that samples of dissolved oxygen varied from 3.4 to 12.4 milligrams in each liter of water, a saturation that is quite sufficient for the usual respiratory processes of the algae. The sources of oxygen are the air above the water, the photosynthetic processes of the algae and other green plants, and to a much

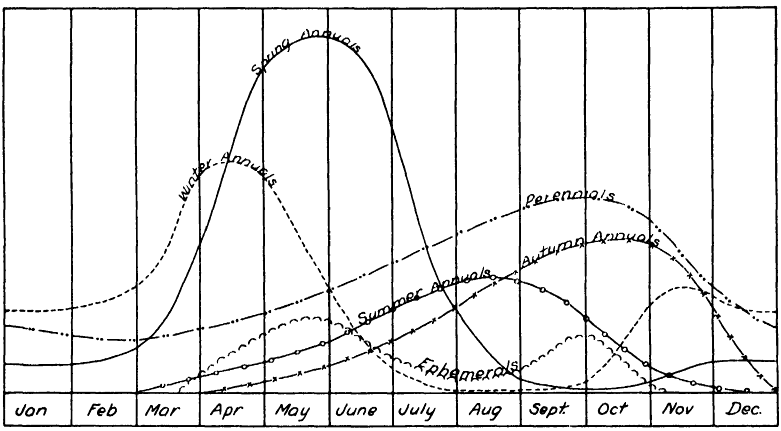



FIG. 8. The annual crop of algae in ponds and lakes is enormously large, because every season has its quota of species. Periodicity of algae in Illinois ponds. (After Transeau.)

lesser extent denitrification. The bulk of the oxygen is derived from the air, although photosynthesis in the algae and respiration in both algae and the animals may temporarily exert a profound influence on its concentration in the lake or pond.

The importance of carbon dioxide in photosynthesis has been stressed in a previous chapter. It occurs in a dissolved state in water and its source is fourfold: the air, surface water entering the lake, oxidative processes within animals and plants or of organic compounds in the water, and dissolved bicarbonates of calcium and magnesium. In calcium or magnesium carbonate, carbon dioxide exists in a fixed or combined state; a loose chemical union is illustrated in a bicarbonate

($CaCO_3 \cdot H_2CO_3$), from which the carbon dioxide may be available almost directly to the algae.

In midsummer the upper layers of water may be very deficient in carbon dioxide due to its use by the algae in photosynthesis. In such cases the algae die of starvation, even though light and temperature may be optimal. So-called soft water lakes with a relatively low potential source of fixed carbon dioxide have a much smaller total crop of algae than hard water lakes with a possible supply two to five times as great.

The ponds of the prairie regions of Illinois are much richer in algal species as well as in individuals than those of the southern part of the state. In very few places in Ohio, except the Lake Erie Region, do we have such luxuriant growth of algae as appears in the Illinois prairies. Perhaps the explanation lies in the relative abundance of necessary mineral salts, particularly nitrates and phosphates.

The distribution of desmids, for example, has been considered for many years to be due to the geological antiquity of the underlying rock. W. and G. S. West held that rocks, older than the Carboniferous, and copious rainfall were the prime factors controlling desmid productivity. More recent data, particularly collections from southern Florida, indicate the importance of the presence of calcium and magnesium salts and the possible absence of excess lime as being the active causative agents. The age of the rocks, then, becomes causal in desmid distribution only in its influence on these mineral salts. Pearsall has associated the abundance of desmids in certain lakes of England with a high ratio of sodium-potassium to calcium-magnesium.

The old theory that algae produce sexually formed spores when the pond is drying up, due to an alleged increase in the concentration of mineral salts at that time, has been pretty definitely "knocked into a cocked hat." Mineral salts are found in greatest quantity during flood times, and sexual activity in the algae appears to have such a hereditary urge that it is almost impossible to control it artificially by chang-

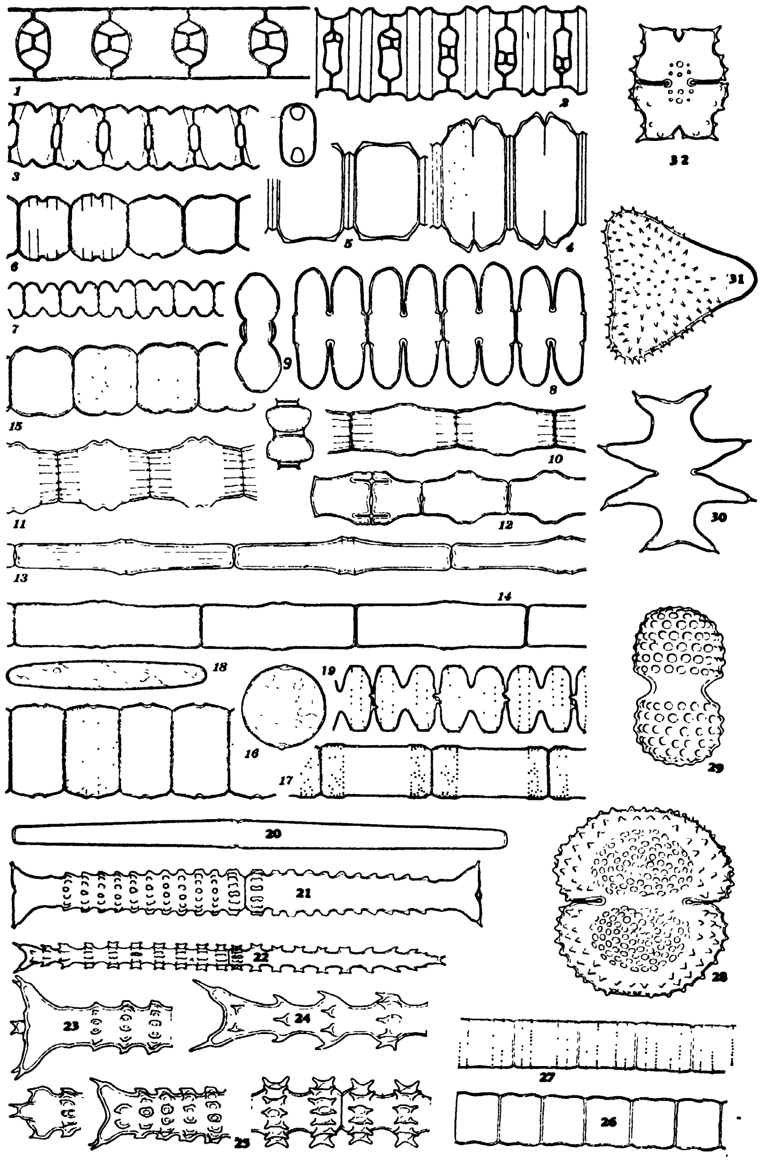



**Plate XI.** **Some desmids are outwardly highly ornamented; others are quite smooth: 1–6, *Desmidium;* 7–9, *Spondylosium;* 10–13, *Bambusina;* 14–17, *Hyalotheca;* 18, *Spirotaenia;* 19, *Sphaerozosma;* 20, *Pleurotaenium;* 21–25, *Triploceras;* 26–27, *Hyalotheca;* 28–29, *Cosmarium,* face and top views; 30, *Micrasterias;* 31, *Staurastrum;* 32, *Euastrum.* (From Taylor, *Papers Michigan Academy of Science, Arts and Letters.*)**

ing the mineral content of the water or, in fact, by doing anything else.

Pearsall seems definitely to have shown that in lakes of Britain a marked correlation exists between diatom productivity and floods, during which time nitrates and silicates are most plentiful. Paucity of diatoms in lakes and ponds is often a matter of silicon deficiency, the "glass walls" of the plants requiring silicon for their manufacture. Apparently fat-producing phytoplankton forms are more likely to occur in calcium-rich lakes and carbohydrate-forming algae in waters poor in lime.

The pH* range of algae is difficult to ascertain with accuracy because of the specific requirements of different algae and due to the fact that the pH reading of the pond or lake may not be at all identical with that minute part of the water immediately adjacent to the alga. Wehrle was able to make a rough classification of algae in ponds of Germany as follows: those growing at pH 3.2 to 4.2; others from 5 to 7; and still others from 7 to 8. There are curious discrepancies. Some species of *Oocystis* and *Trachelomonas*, for example, may be found almost in the entire range. A few algae may occur at the lower and higher pH ranges but not in the intermediate ones.

The concentration of soluble inorganic salts is higher in very alkaline than in very acid waters. Moderately acid waters probably contain the greatest abundance of species. Perhaps a safe conclusion is that algae really grow—whether optimally or not we have yet to learn—in a very wide range of hydrogen ion concentration, but maximal abundance obtains only within rather narrow limits.

A pond or lake then is an aqueous cosmos where practically all the elemental forces of nature are at work. Food is made, food is used. Animals eat algae and animals eat other animals. Both algae and the animals grow and multiply in their season and then die. Their decomposition products may again be used by the algae in food syntheses, and the cycle begins all over

* A pH of 7 is considered neutral, less than 7 acid, and more than 7 alkaline.

again. In such bodies of water occur practically all the fresh-water algae known to man: the greens, the blue-greens, the yellow-greens, the golden-browns, and some reds; *Volvox* and *Spirogyra*, desmids and diatoms, *Cladophora* and *Ulothrix*, *Euglena* and *Peridinium:* in all some 15,000 species and countless millions of individuals.

## Chapter V

# ALGAE OF STREAMS AND RIVERS

Most of us when looking at maps want to know the location of Cincinnati, or the shortest route from Chicago to the Yellowstone, or the relative sizes of Texas and Rhode Island, or the region where the tall corn grows, or the place where Lee surrendered to Grant in 'sixty-five. If we examine a relief map of North America we note mountains and plains, lakes and valleys, and river systems. Books on geography tell us about the Ohio River, the Wabash River, the Embarras River, the Mississippi, and the Missouri. Did it ever occur to you that each of these is merely an arm, a part of a great drainage system? If you desire pleasant diversion some evening, place a large map of North America on a table and beginning at New Orleans trace a water route up the Mississippi until you come to the source of some river or stream. How many different sources are there? The Father of Waters at New Orleans is a composite of many rivers, of multitudinous streams, and of millions of smaller tributaries, draining altogether an area of about a million and a quarter square miles.

Apparently the early geographers made an error in considering the Missouri River a branch of the Mississippi. The Mississippi-Missouri is perhaps the parent stream, or at any rate it is the longer, reaching over 4000 miles from source to mouth. Some single-celled algae, like *Chlamydomonas*, rapidly reproduce by simple fission; that is, one plant divides, forming two plants just like the parent. The daughter cells continue such division and their progeny may do likewise. Starting at the source of the Mississippi-Missouri River with one alga capable of forming a new generation every twenty-four hours, how many individuals would there be by the time the water reached New Orleans, if the division continued at the same rate? The resulting number is extraordinary: 800,000,000,-

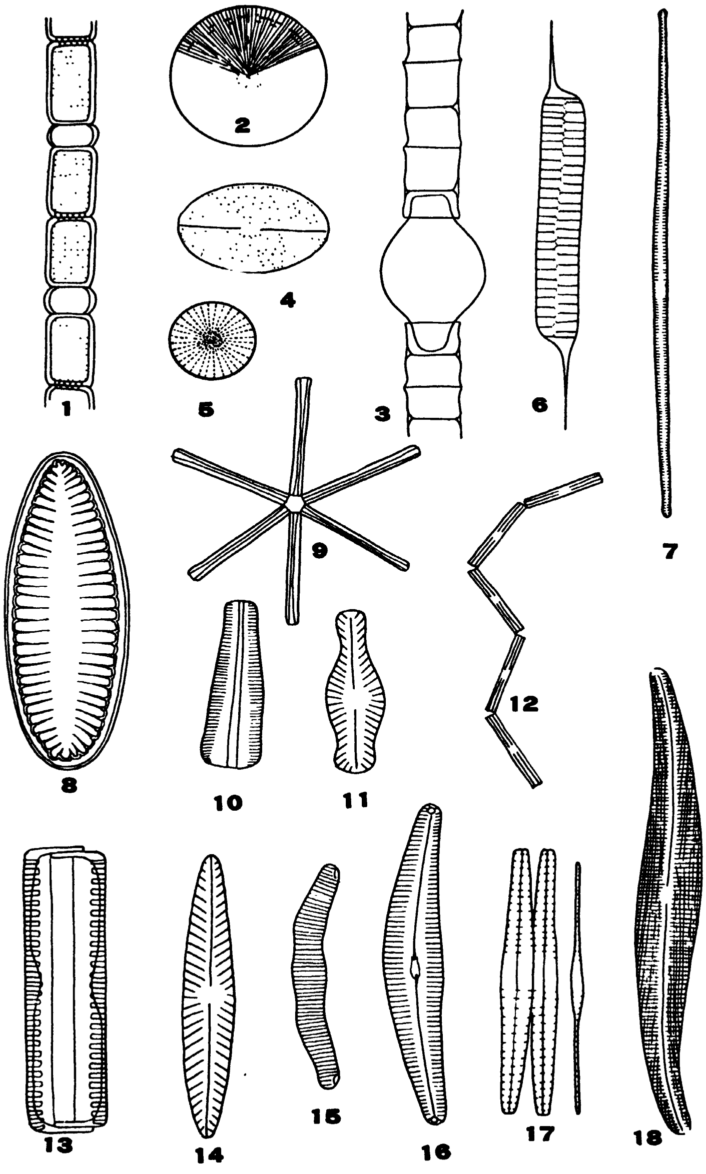



**Plate XII.** Freshwater diatoms are represented in both quiet and running water by many species: 1–3, *Melosira*, (part of filament, end view of cell, and auxospore formation); 4, *Cocconeis*; 5, *Stephanodiscus*; 6, *Rhizosolenia*; 7, *Synedra*; 8, *Surirella*; 9, *Asterionella*; 10–11, *Gomphonema* (girdle and valve views); 12, *Tabellaria*; 13–14, *Navicula* (girdle and valve views); 15, *Eunotia*; 16, *Cymbella*; 17, *Fragilaria*; 18, *Gyrosigma*.

000,000,000,000,000,000,000,000,000,000,000. The oceans, lakes and rivers of all the world—and not just one river at its mouth—could not contain such a mass at one time.

Something about such numbers is obviously wrong. It might of course be the arithmetic. The simple fact is, however, that such continuous accumulation of algae does not occur in a river, or in fact for that matter in any body of water. Why not? What factors influence the algal productivity of streams and rivers?

The current of a river or stream fluctuates a great deal from source to mouth, depending upon the amount of rainfall, shape of bed, slope, and volume of water delivered by the tributaries. The grade may be slight and long, as in much of the Mississippi system; short and steep, like those of Southern Chile; both abrupt and gentle, as shown by some parts of the Ohio River system. Possible algal habitats are thus all gradations from the almost imperceptible flow of the meander to the precipitous descent of waterfalls and cataracts. It ought not to be surprising then that the algal population of running waters is somewhat difficultly catalogued.

In swiftly running waters the characteristic algae are those with so-called holdfast cells or similar structures which enable them to remain attached to stones, rocks, and rooted vegetation in spite of the current. Freshwater red algae, like *Lemanea*, grow in most rapid torrents and waterfalls; those such as *Batrachospermum* develop on the bottoms of moderately cool, slightly alkaline, rapid waters of small streams. Probably the most common alga in streams of temperate regions is the green *Cladophora*, attached basally to stones and rocks and other substrata, often extending many feet with the current. It is this plant which squirrels, cattle, and other vegetarians have been observed eating, doubtless only as an item *ad gustum* rather than the *piece de resistance* of their diet. In very shallow waters issuing as springs, the tubular felt (*Vaucheria*) forms large mats. Other algae without holdfast cells may remain on various substrata in spite of the current, due to copious secretion of mucus (pectic compounds) in which

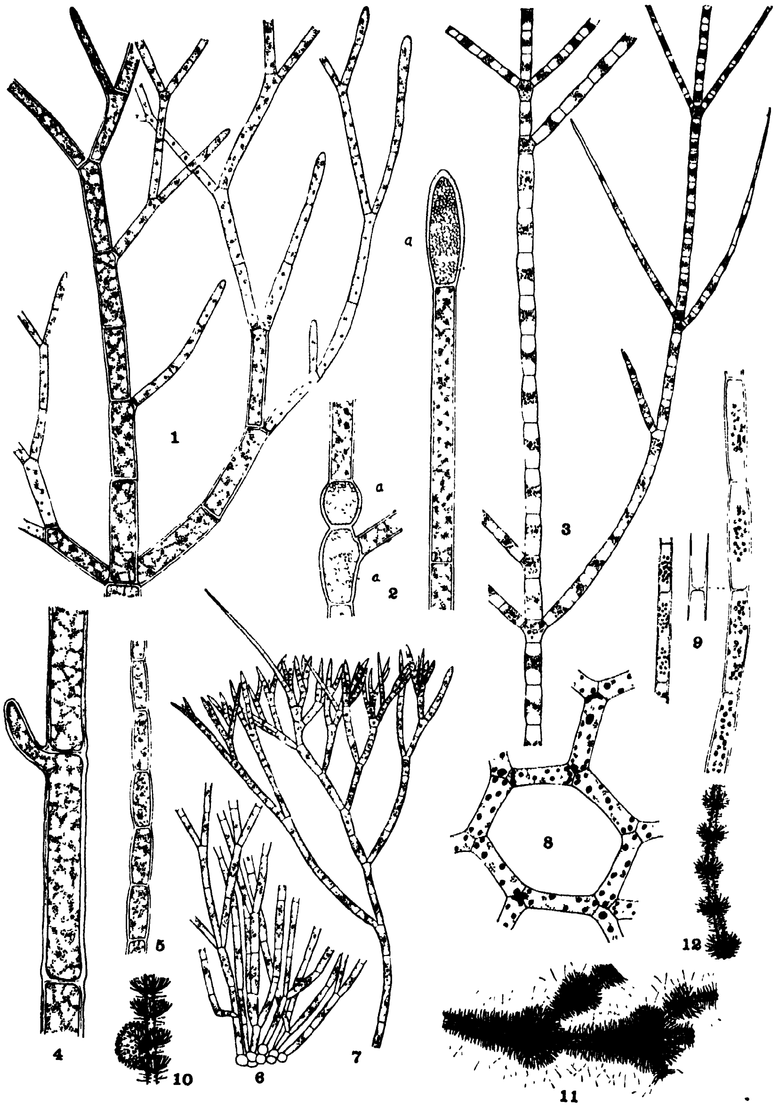



PLATE XIII. The larger branched algae are nearly always attached at some period of their life cycle: 1, *Cladophora;* 2, *Pithophora* (a, akinete); 3, *Stigeoclonium;* 4–5, *Rhizoclonium;* 6–7, *Chaetophora;* 8, *Hydrodictyon;* 9, *Tribonema* (a single H-shaped piece shown separately); 10, *Batrachospermum;* 11–12, *Sirodotia.* (6, 7, redrawn from Hazen; 10–12, from Skuja.)

the cells are imbedded. The delicate strands of *Tetraspora* and *Draparnaldia* as well as the slimy balls of *Chaetophora* are among the first of the brightly green algae of spring, and they occur in rapidly moving water of streamlets well supplied with nitrogen and phosphate compounds. Desmids, diatoms, blue-greens, as well as other greens are similarly attached, particularly in the cooler waters in spring. Shifting sandy bottoms of swiftly moving streams are devoid of vegetation, and have been aptly termed "aquatic deserts."

The plankton of moderately slow rivers and streams has been studied with varying degrees of assiduity for four or five decades. Such rivers as the Oder, the Danube, the Volga, and Thames in Europe; the Yang-tse of China; and the Illinois, the Mississippi, the San Joaquin, the Ohio, and the Hocking of the United States have been surveyed with considerable care.

Generally speaking the plankton of rivers is distinct from that of lakes; in fact, this feeling on the part of early investigators gave rise to a special term—the potamoplankton. The fluviatile environment is in many ways different from the limnetic. Rivers contain no thermocline and hence no periods of winter and summer stagnation; there is no permanently cold lower stratum. The plankton that has become entirely adapted to river conditions is much less rich in both species and individuals than is the truly limnetic plankton. Catastrophic changes of the water are more numerous, effects of pollution are more serious, and possibilities of a good "seed bed" are much more remote than in most lakes and ponds. The dependence then of rivers upon their shallower tributaries, backwaters, and ox-bows for the source of most of their plankton flora seems evident. Streams are rarely entirely destitute of raw materials, as may be the case in some lakes, and probably on the whole are better supplied with nitrogenous compounds. The truly autopotamic planktons are generally diatoms. The multiplication of the algal constituents of a stream, whatever their source, may take place as they are being carried downstream. It has long been known that,

other things being equal, the less rapid the stream the more individuals in the plankton. Slow-moving waters may often be covered in summer with "blooms," usually nearly pure cultures of *Euglena*, *Chlamydomonas*, or sometimes diatoms or blue-greens.

Methods of studying river plankton are similar to those employed on lakes. A given amount of water (usually a liter) is collected at desired depths in specially constructed samplers

PLATE XIV. Stream algae growing on boulders: left, covering of *Phormidium;* right, crust of *Chamaesiphon.* (Upper portion of boulder to the right out of water.) (From Fritsch.)

and then centrifuged. Centrifuging as a tool for plankton work was initiated more or less independently about 1897 by three limnologists: Kraemer, Kofoid, and Juday. The liter of water may be centrifuged down to about 10 cc., from which 1 cc. is transferred to a Sedgwick-Rafter counting cell. By actual enumeration of the individual algae in the counting cell under a microscope, and by the application of the proper factor, the number of plankton forms in the liter of water may be computed. When exact quantitative data are not desired, one may secure representative samples of plankton in considerable numbers by straining through a tow net made of No. 20 bolting silk. The latter method of course does not "catch" the very small algae—the so-called nannoplankton—which pass through the small meshes of the net.

The plankton population of different rivers varies enormously. They nearly all agree, however, in the preponderance of diatoms, followed (often not very closely) by greens and blue-greens, and lastly other groups. A cubic meter of water may contain, for example, 8,000,000,000 diatoms, 150,000,000 greens, and some 500,000,000 blue-greens. The ratio in other samples may be $10:1:\frac{1}{2}$. The productivity at any one time is dependent upon so many factors that such ratios can give only some general idea of relative abundance. Most river studies are also in agreement as to the quantitative preponderance of the algal plankton over the animal plankton.

The presence of diatoms in such large numbers in streams at certain seasons seems to be correlated more with floods than with temperature. Sudden rises of the temperature in the waters of tributaries may free millions of diatoms because of rapid solution of the mucus by which they are attached to various substrata. The main stream in such a case is merely the recipient and not the source of the sudden wave or pulse. In the river Thames maximal diatom production occurs in winter during flood times when the suspended matter, especially silica, is high. It certainly is difficult to correlate winter production with favorable temperature. High productivity of diatoms in spring usually follows periods of floods when organic matter with nitrates and silicates is very abundant. At any rate the floods bring into the main stream the accumulated plankton of backwaters, lakes, and tributaries. In other cases an autumn maximum of diatoms may occur. Rivers of countries having severe winters are often destitute of any plankton during that season.

The plankton of tributaries and backwaters is frequently somewhat different from that of main streams and is usually richer in greens and blue-greens. The fluviatile plankton, while a not wholly separate and distinct flora, is nevertheless sufficiently different from that of lakes and ponds to warrant its separate consideration and study.

A stream or river, then, represents an environment of great fluctuation and variation in current, volume of water, tur-

bidity, light penetration, availability of necessary salts and other raw materials, and conditions of bottoms and shores. These factors and their interrelations govern the algal population of the river or stream, and there can never be an unlimited harvest.

## Chapter VI

# ALGAE OF THE SEA

Most of us who live inland think of the world in relation to the soil—the ground—the earth. It is true that river systems permeate the land, lakes and ponds dot the landscape, birds and airplanes soar with the clouds, and the sun is millions of miles away. In a very large measure, however, our outlook is terrestrial: rivers and ponds have land beds and bottoms and may become dry, the flying bird must eventually seek rest, giant trees are rooted in soil, and even the highest mountains are merely upward extensions or extrusions of our terraqueous globe.

Our dependence upon the waters of the sea is very real, especially as regards rainfall. It is largely the water vapor from gulfs and seas and oceans that, blown over landed areas, condenses upon cooling into what the weatherman measures as precipitation.

The magnitude of the oceans is difficult for us landlubbers adequately to picture. Of the nearly 197,000,000 square miles of surface area of the earth, over 139,000,000 square miles are ocean. This is quite significant when compared to the approximately 1,000,000 square miles of lakes and rivers. The volume of all ocean basins has been estimated to be some 334,500,000 cubic miles. The average depth of the ocean below sea level is about $2\frac{1}{3}$ miles; the deepest depth yet ascertained, of more than six miles, lies near the Philippine Islands.

To a great many people the vegetation of the ocean is either non-existent—a great empty waste—or a part of the supposedly vast meadow known as the "Sargasso Sea." In Segar's superlatively intriguing comic strip "Thimble Theatre," you will recall Popeye's ocean voyage in which the vitamin-producing cow was provided with "fresh grass." The one-eyed sailor merely harnessed the creature suspended from the end

of a protruding beam in such a way that she could eat "sea weed" as the ship sailed its course. Although Segar does not mention it, Popeye and his crew were doubtless in the "neighborhood" of the Sargasso Sea.

The area has been seriously described in the past by various authors as an aquatic meadow nearly as large as Texas and so densely populated with seaweed as to impede navigation.

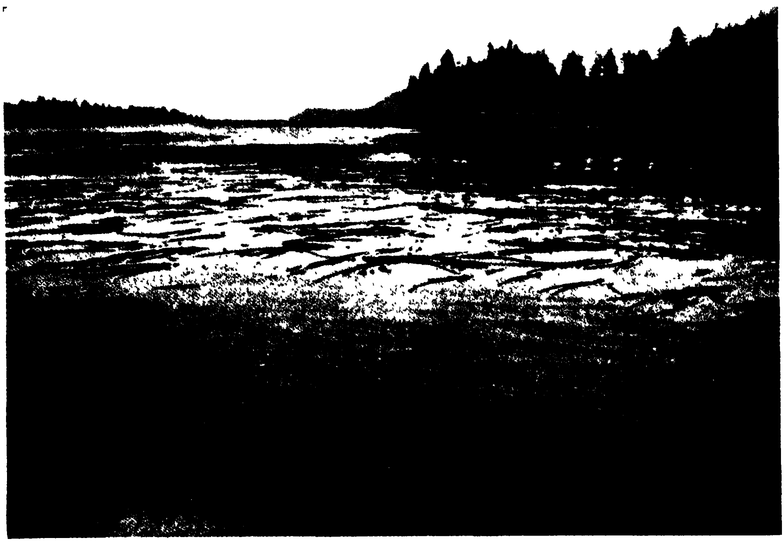


PLATE XV. Large bed of *Nereocystis* in Alaskan waters. (Report No. 100, Bureau of Soils, U. S. D. A.)

Linnaeus wrote: "Crescit in omnibus fire rupibus aqua marina apertis circa Jamaicam, alliisque Americae pluribus, unde a fluctibus abruptum, magnamque partem maris Americani borealis implet, ut pratum viride diceret spectator remotus." The seaweed area was observed by Columbus on his voyage to the New World and its berry-like air bladders led him to suspect that land was near.

The Sargasso Sea is now known to be a tract in the North Atlantic Ocean covered in scattered patches by the floating seaweed, *Sargassum*, which the Portuguese seemed originally

PLATE XVI. *Sargassum*, from the coast of Florida, characteristic oı the Sargasso Sea. (From Smithsonian Institution Series.)

to have called "sargaço." It lies roughly in latitude 25–31 N. and in longitude 40–70 W. High winds and currents may alter its area and density, and fragments may be carried to the shores of New England and to the coast of northern Europe. The *Sargassum* of the Sargasso Sea is a pelagic perennial which must at some time have been torn loose from attached plants on coasts to the southwest. Its attached ancestor can perhaps never be definitely known. It propagates by fragmentation, never fruits, and probably consists of several distinct species. Occasionally attached species of *Sargassum* may occur in the floating "sea," but they can readily be distinquished from the pelagic forms. The *Sargassum* is accompanied by other algae as well as amphipods, crabs, mollusks, and fish: some seldom found elsewhere, others characteristic of the littoral zones.

What is the true status of the vegetational productivity of the sea? To answer this question with any degree of accuracy it will perhaps be necessary first to analyze the nature of this salty aquatic habitat. Marine biologists have brought to light many data concerning not only the kinds of living things found in the ocean but also the effects upon plants and animals of varying temperatures, salinities, depths, pressures, currents, and other physical and chemical conditions.

Some thirty-two elements are known to occur in sea water, chief of which are oxygen, chlorine, bromine, sulphur, sodium, magnesium, calcium, potassium and silicon. The saline composition is due largely to chlorides and sulphates with a smaller percentage of carbonates and bromides. These chemical compounds are of course responsible for the increased density of sea water over fresh water. The proportions of the salts remain surprisingly constant except for the increased quantity of lime at greater depths. Bigelow states that whether samples are taken in the Atlantic, in the Pacific, or in the Indian Ocean, for various latitudes the total solutes are approximately 54% chlorine; 31% sodium; 4% magnesium; 1% potassium; 1% calcium; 0.2% bromine; 8% of sulphate radicals; and 0.2% of carbonate radicals. Perhaps outside of

fresh water and the atmosphere, ocean water has the most uniform composition of any substance on earth. Sea water is distinctly alkaline, and apparently its alkalinity never varies materially beyond the requirements for marine life.

Nitrogen, oxygen, and carbon dioxide are absorbed directly from the atmosphere, although the latter two are subject to considerable local variation in amount due (1) to photosynthesis in plants and respiration in both plants and animals and (2) to oxidation of organic matter *in situ*. Gases are supplied to depths lower than the surface by circulation of the ocean water and by such oxidations of organic material as may occur. Each gallon of sea water has approximately 1.6 cubic inches of oxygen as compared to 1.3 cubic inches in a like volume of fresh water.

The temperature of the ocean water varies from about $-2°$ C at the poles to nearly 30° C at some points within the tropics. Seasonal variations in temperature do not occur at depths of over 500 feet. Ocean water below depths of a mile has a constant temperature of around 2° C although at considerable depths the freezing point of fresh water may be reached.

The purest "ocean blue" probably occurs in certain tropical and subtropical areas of the Indian and Pacific Oceans and also in the "Sargasso" where Krummel reports that white discs are visible at depths of 200 feet. Variations in color toward green are due to local disturbances largely in the accumulation of plankton and mineral substances. Pure water is blue because the non-absorbed rays are reflected; if plankton or mineral substances be present, red and yellow rays are reflected and the water appears green.

For purposes of floral and faunal studies the ocean is conveniently but scarcely satisfactorily divided into three zones: the littoral, the shallow water, and the deep water or abysmal. The littoral zone varies from rugged cliffs to sandy shores and is subject to the effects of the rise and fall of the tides. The salinity of the water is subject to change because of fresh-water inflow from streams and rivers. The wind, the tide, and

the influence of rainfall on stream flow cause drastic changes in temperature and water supply. The shallow water area, usually flat and extensive though sometimes with swiftly descending bottom, includes water not exceeding a hundred feet in depth. The water is shallow, well lighted to the bottom, and subject to a lesser degree to the effects of tides, winds, and rivers. The abysmal zone has a temperature of two or three degrees above the freezing point, is practically dark, maintains a pressure of about a ton per square inch for every mile in depth, and remains practically uniform in temperature and chemical composition.

The depth at which certain marine algae will carry on photosynthesis at a maximum rate has been reported upon by several investigators. It has been supposed that the red coloring matter (phycoerythrin) of the red algae acted in a capacity similar to chlorophyll in absorbing rays of light useful in photosynthesis. As noted in an earlier chapter it is largely the red rays that are used in photosynthesis. Many shade plants have, however, been shown to use the blue rays in the same way.

Tschudy in some interesting experiments with marine forms observes that most photosynthesis occurs in both red and brown algae at depths between 5 and 10 meters. On cloudy days maximum photosynthesis may occur at the surface. Red algae utilize light at depths of 20–25 meters, but the brown algae cannot make carbohydrates in more than 15 meters of water. It is equally true that green algae are recorded from much lower depths than these and that many red algae grow well at the surface.

It seems probable that the red coloring matter instead of serving as a photosynthetic pigment acts as a color screen and that algae of greater depths are able to use light of the shorter wave lengths.

Such in brief is the environment of the sea. Mention has already been made of the *Sargassum* of the Sargasso Sea. What other algae live and grow in the ocean?

The seaweeds, as the term is popularly applied, are macro-

scopic marine algae belonging chiefly to the reds and browns and less particularly to certain greens and blue-greens. They are more or less common in many parts of the world but perhaps reach maximal size and productivity along rocky coasts in the temperate regions of both hemispheres. Most seaweeds grow in comparatively shallow water, seldom being

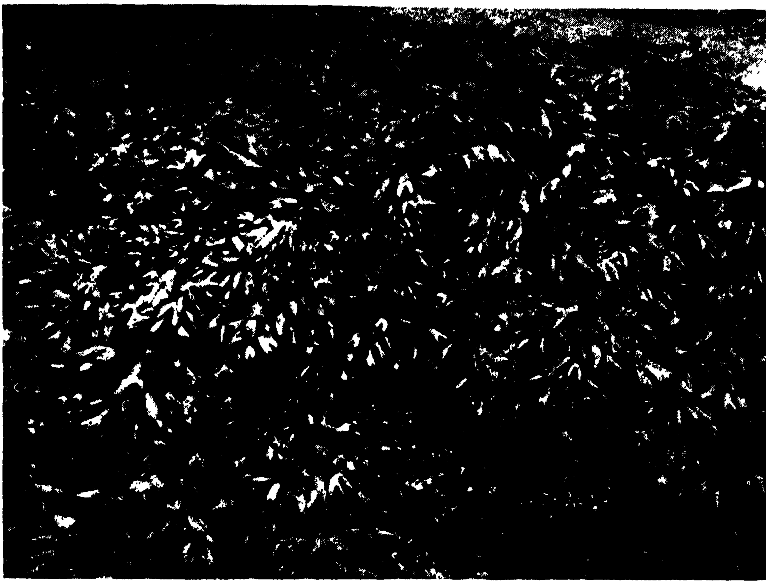


PLATE XVII. *Fucus*, the rockweed. San Juan Island, Washington. (Photograph by A. W. Haupt.)

found at depths greater than 200 feet, although W. R. Taylor reports some *Caulerpas* from the Dry Tortugas down as far as 300 feet.

"Typical" brown seaweeds may be represented by the bladder kelp,* *Nereocystis*, of the Pacific. It forms extensive beds from the southern part of California to the Aleutian Islands. It grows in water from 10 to 100 feet deep, reaching its best development in active waves or pronounced currents. A hollow, more or less globose vesicle filled with air or gas

* Other common names are bull kelp, ribbon kelp, and sea otter's cabbage.

terminates a long slender stalk attached basally to the sea bottom. From the top of the floating enlargement arise several long, leaf-like blades. In spite of accounts of early writers, the bladder kelp seldom reaches a length of 150 feet. Its growth rate is very rapid considering that it is in many cases an annual. Incidentally *Nereocystis* is so definitely associated with

PLATE XVIII. *Pelvetia* on rocks of tidepools near Laguna Beach, California. (Photograph by A. W. Haupt).

rocky shoals and reefs that it is important to navigation by small craft in shallow water during summer.

Extending from Santa Barbara, California, to Lower California occurs the elk kelp or sea pumpkin or sea orange, *Pelagophycus*. Having about the same geographic range as *Nereocystis*, the giant kelp or vine kelp (*Macrocystis*) grows for the most part in densely compact beds in water from 20 to 70 feet deep. It is a perennial, sometimes reaching a length of nearly 200 feet. *Pterygophora* of the Puget Sound region shows in its stipe apparently annual "rings." The rings to-

gether with other observations seem to indicate that single plants of *Pterygophora* may live for nearly a quarter of a century. *Laminaria*, another kelp or devil's apron, is a coarse

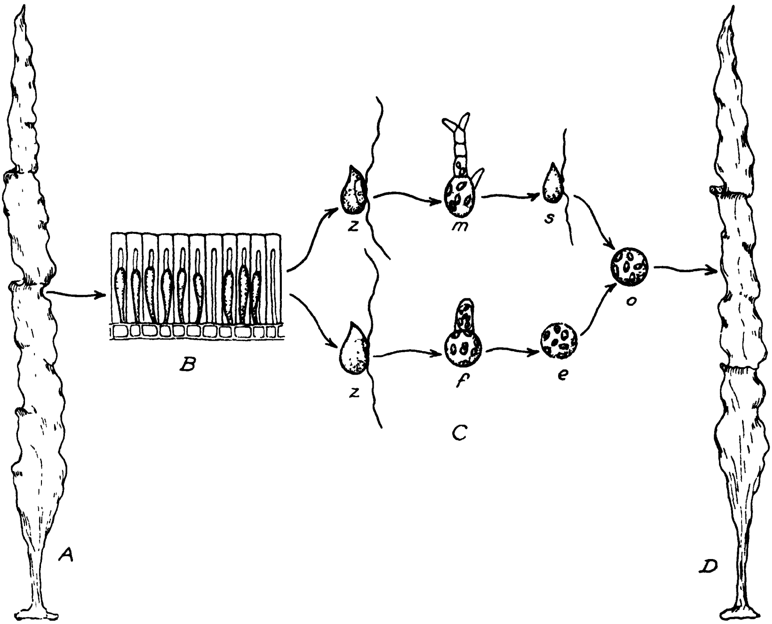



FIG. 9. Diagrammatic representation of life history of a kelp, *Laminaria* or devil's apron: A and D, the vegetative plant; B, section through portion of surface of kelp, showing sporangia; C, formation of gamete-producing plants (z, zoospore from a single sporangium; f, egg-forming plant; m, sperm-forming plant; e, egg; s, sperm; o, oospore). This is a good illustration of alternation of generations between a zoospore-producing plant and a gamete-forming plant.

leathery leaf-like alga attached to stones by conspicuous holdfasts.

Perhaps the best known and most widely distributed of the brown algae is *Fucus*, the rockweed. It occurs in great masses on stones and rocks in arctic and temperate regions and is alternately covered and uncovered by the flow and ebb of the tides. The plant is coarsely ribbon-like, is covered with mucilage, and has branches terminating in air bladders. The

mucilage appears greatly to prevent desiccation at low tide. Other examples of brown algae are *Costaria* with rib-like veins, the sieve-like *Agarum*, *Alaria* with winged leaf-blades, and the long *Chorda* about the diameter of a pencil but reaching a length of from 5–20 feet and named mermaid's fish line.

The life history of a kelp may be represented briefly by that of *Laminaria* (Fig. 9). The blade develops numerous large patches with many sporangia in each. The zoospores from the sporangia grow into archegonial or antheridial filaments, which produce the female and male gametes. The fertilized egg or oospore resulting from the union of the sperm and egg grows into a big *Laminaria*. Thus the small filament alternates with the "kelp" as most people know it. Such a condition is known as an alternation of generations; that is, the big plant is the sporophyte (spore forming) and the filament is the gametophyte (gamete producing), and one generation always gives rise to the other.

The red algae are frequently termed the sea mosses because of their superficial resemblance to a delicate moss. Most people have at some time or other purchased little folia of pressed red algae to prove to their friends they have been near the ocean. The reds as a group are scarcer in colder seas and most abundant in tropical and warm temperate waters. It was formerly believed that their red color enabled them to grow at greater depths than other algae but this is now considered doubtful, because algae of other colors are found at great depths. The reds are multicellular and much smaller than the browns. The reproduction is very complex in most forms and we shall indicate it very briefly as it occurs in *Nemalion* (Fig. 10). The threads of *Nemalion* are made up of numerous filaments, branching and producing at the tip larger cells which form both antheridia and carpogonia. Each carpogonium narrows terminally into a long neck (the trichogyne) and rests basally on a few flattened cells (the carpogonial branch). This whole structure is sometimes referred to as the procarp. The antheridia bear spermatia each of which contains two nuclei. The spermatium is not motile. It comes to

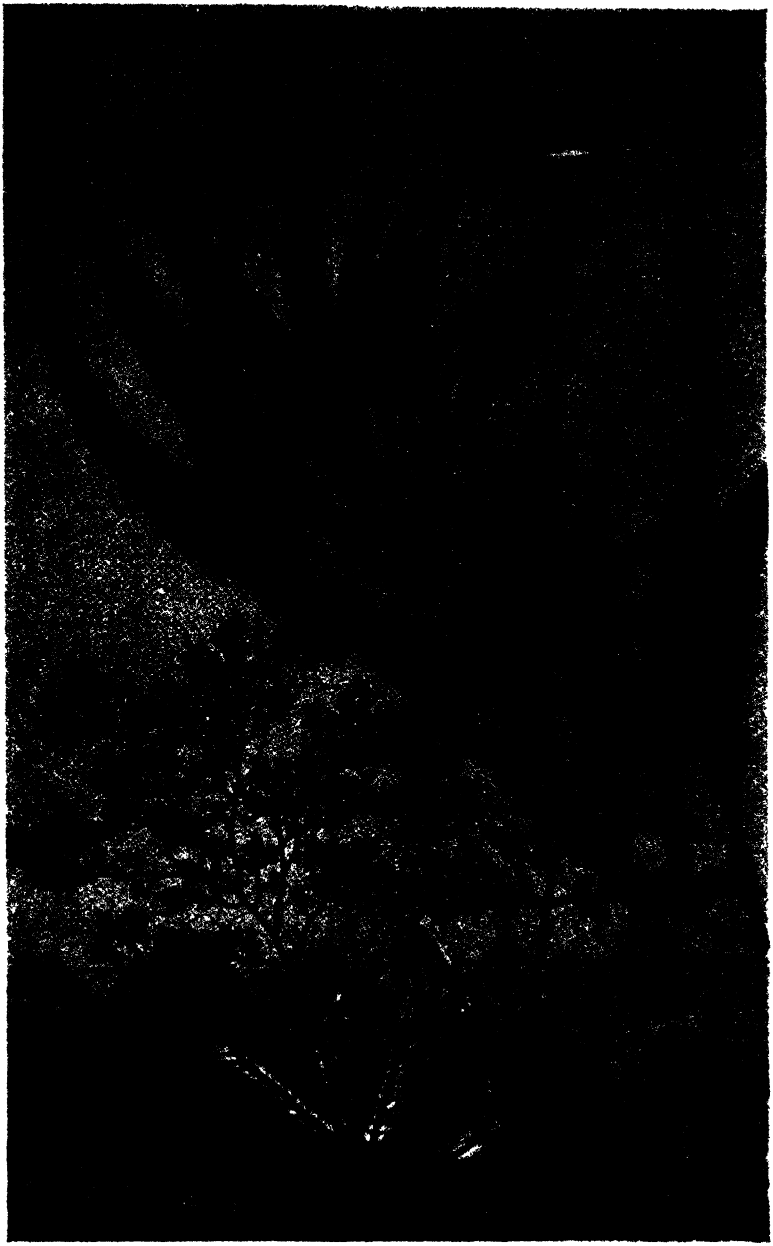


PLATE XIX. A composite scene of living red and brown algae from widely separated areas in the Atlantic and Pacific oceans. By E. Cheverlange. (From Smithsonian Scientific Series.)

rest on the trichogyne tip and its sperm nucleus moves to and unites with the nucleus in the carpogonium. The fertilized egg resulting produces several chains of cells, the end cell (a carpospore) forming a new plant. The whole mass of cells

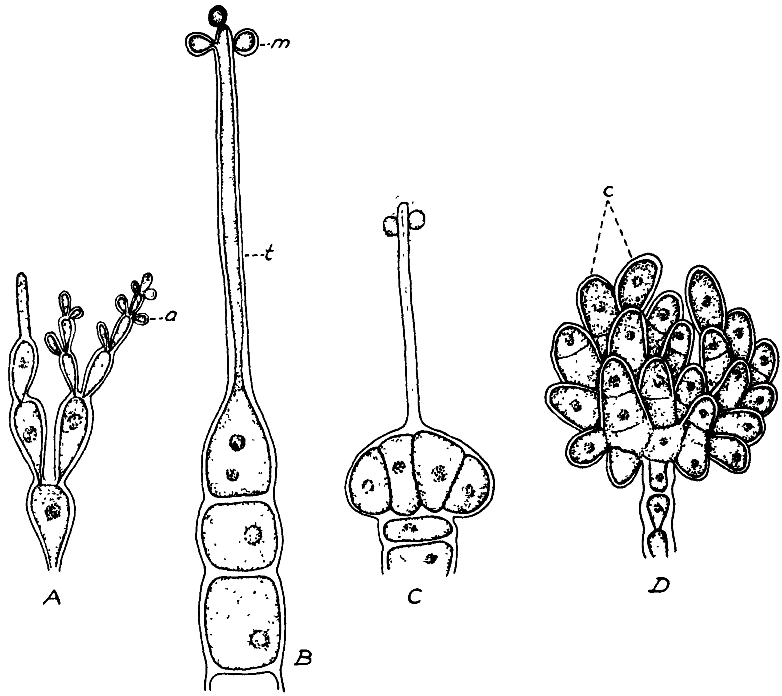



FIG. 10. Diagrammatic representation of the life history of a marine red alga, *Nemalion*: A, portion of plant bearing antheridia (a), containing male cells; B, end of a branch, with female cell (carpogonium) terminating in a (t) trichogyne, to which are attached three male cells; C, further development of the female cell; D, cystocarp made up of many filaments, each of which develops a carpospore (c).

produced by the carpogonium is the cystocarp. The red algae produce no flagellated cells in spite of their long-time aquatic habitat, and this absence must be disconcerting to those teleologists who have a structure arise every time there is "need" for it.

Some examples of red algae besides *Nemalion*, which C. J.

Chamberlain describes as a pink or reddish mass of slender slippery "worms" hanging from the rocks at low tide and floating weakly and partly erect at high tide, are: *Polysiphonia* in shallow water of both Pacific and Atlantic coasts; *Chondrus*, the Irish moss of commerce; *Rhodymenia*, the dulse; *Delesseria;* the feather-like *Plumaria*. Forms like *Ceramium*, *Lithothamnium*, *Corallina*, and *Lithophyllum* become incrusted with lime and help build up coral reefs. Plant formations like those of *Corallina* are reported from the Cambrian over a hundred million years old.

Many uses are made of the seaweeds, particularly by those who live along shore. *Laminaria*, *Ecklonia* and *Fucus* are sources of iodine; many species serve directly as fertilizers; *Nereocystis*, *Macrocystis*, and *Pelagophycus* yield considerable quantities of potash; *Chondrus* when dried enters into the making of some puddings and jellies; a candied "fruit" known as seatron may be made from stalks and bladders of *Nereocystis;* *Rhodymenia* is occasionally eaten raw as a relish; the Japanese make a sort of glue out of *Gloiopeltis* and use *Gelidium*, *Porphyra*, and many other kelps as food; and some of our laboratory agar originally came from *Gracilaria*, "Ceylon moss." Further mention of the seaweeds will be made in a later chapter where the economic aspects of algae are discussed.

The marine green algae can be represented first by the ubiquitous *Cladophora*. Perhaps no other alga has such a universal distribution not only in the sea but in freshwater as well. Exposed rocky shores, bays, lagoons, and marshes all abound in *Cladophora*. F. S. Collins has written that "there is probably not a stretch of a few rods in all New England (except sandy beaches), reached by salt or brackish water, where Cladophoras cannot be found, at least in spring or summer."

*Cladophora* is easily recognized as an attached, branching, filamentous, monosiphonous plant with multinucleate cells. Reproduction occurs by the formation of zoospores and gametes from practically any cell. There are many species in

**Plate XX.** A composite scene of living green and red algae from the Atlantic and Pacific oceans. By E. Cheverlange. (From Smithsonian Scientific Series.)

the genus, some poorly described. Distinctive characters used to differentiate species are size of plant, size and shape of cells, amount of branching, presence or absence of holdfast cells, and color.

Other forms of green algae of the sea are *Ulva*, the sea lettuce; the essentially tubular *Enteromorpha;* the flattish *Monostroma;* the umbrella-like *Acetabulum;* the branching almost thalloid *Codium;* the calcified *Halimeda;* the calcareous, fan-shaped *Udotea;* the club-shaped *Bornetella; Dasycladus* with its acropetal whorls of branches; the tufted (also calcareous) *Penicillus;* and the deep growing *Caulerpa.*

The species of blue-greens are highly gelatinous and may be represented by such common forms as *Oscillatoria*, *Lyngbya*, *Calothrix*, and *Rivularia.*

The seaweeds, occupying the littoral and shallow water zones, are usually the most conspicuous, but they are by no means either the most important or the most abundant constituents of the algal flora of the ocean. The great producers of carbohydrates, fats, and proteins are the plankton forms which occur in the shallow water zones where light is ample even to the bottom, where aeration is maximal, and where change of water from incoming streams is frequent.

In many parts of the ocean the water is literally teeming with animals: mammals like whales, seals, porpoises; reptiles including turtles and sea snakes; fishes of innumerable hues, shapes, and sizes; crustacea, spiders, and mollusks; jelly-fishes and sponges; and countless microscopic protozoa, radiolaria, ciliata, and flagellata. Writers of several decades ago were amazed at the vast numbers of animals in the open sea and commented upon their "insatiable rapacity." As a matter of caution it must not be inferred from this that all areas in the sea are so plentifully populated. As W. E. Allen has pointed out, there are indeed vast volumes of ocean water that have negligible populations at some or all seasons of the year.

What accounts in many places from the poles to the equator for these aquatic hordes and why, like the gingham dog and the calico cat, don't they "eat each other up"?

PLATE XXI. The brown alga *Pelagophycus* from the Pacific. (From the Smithsonian Scientific Series.)

The answer lies principally, though not wholly, in the microscopic algae—"the primary food supply of the sea." The plankton forms of marine algae are many, but our attention will be given primarily to the diatoms. The structure, growth, and reproduction of freshwater diatoms are discussed in a previous chapter. Sea diatoms differ only in species and genera,

PLATE XXII. The palmlike *Postelsia* and the festoon-forming *Lessoniopsis*, brown algae from the Alaskan coast. (From the Smithsonian Scientific Series.)

in variety of ornamentation, and in relative abundance of different forms.

Marine diatoms are considered to be so important that they have been referred to as the grass of the sea. Many other marine plants, as for instance the so-called eel-grass (*Zostera*), contribute to the sustenance of marine animals, but the diatom is the plant *par excellence* in their diet.

To realize the importance of sea diatoms one has only to recall the abundance of aquatic animals in the ocean. The animals feed upon each other, to be sure, but ultimately the food cycle must begin with an organism capable of synthesizing foods from inorganic substances. These organisms, as

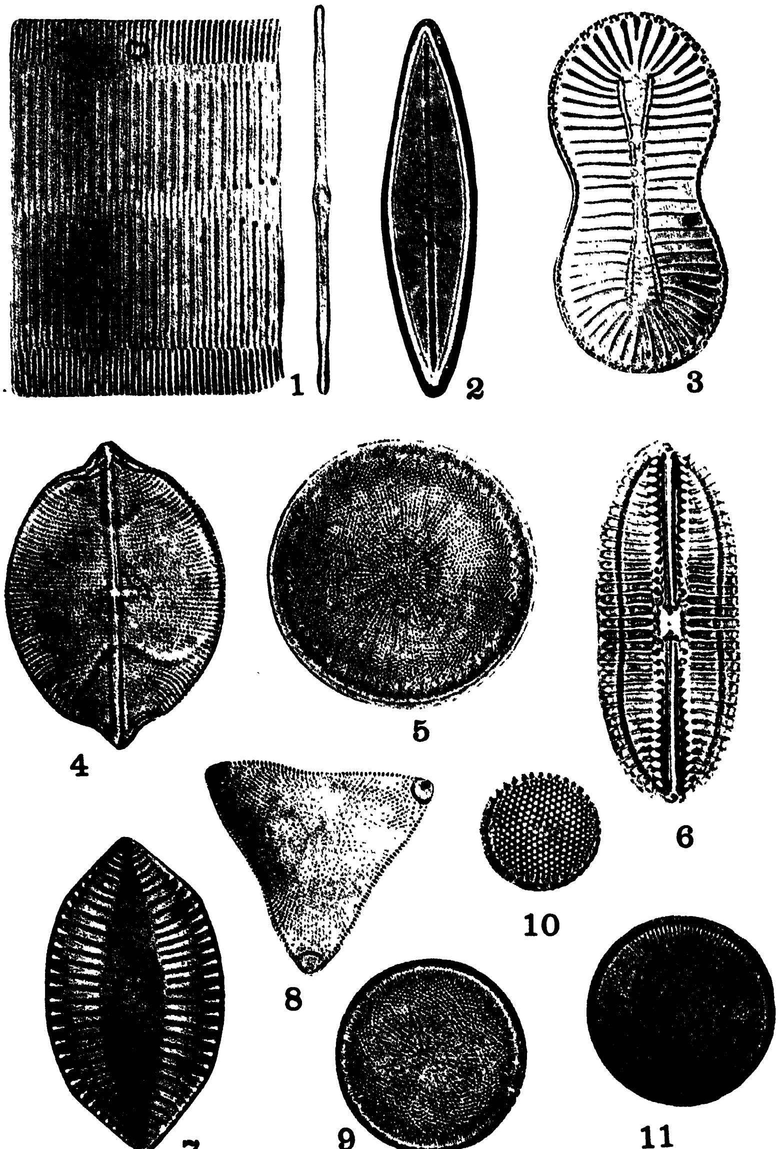



PLATE XXIII. Marine diatoms: 1, *Rhabdodema;* 2, *Navicula;* 3, *Surirella;* 4, *Navicula;* 5, *Coscinodiscus;* 6, *Navicula;* 7, *Cocconeis;* 8, *Trinacria;* 9, 10, *Coscinodiscus;* 11, *Cyclotella.* (From Mann.)

mentioned in a previous chapter, must be plants containing chlorophyll—such are the diatoms. Mann analyzed samples of algae from the Shackelton Expedition to the South Pole and found a large percentage of diatoms. The diatom primarily then makes possible animal life in the Antarctic. Similar claims may be made for diatoms and other algae of the ocean as a whole.

It must not be supposed that the floating diatoms are necessarily the most important. It is true that in the open sea they constitute practically the only plant growth. In fact Mann has shown that bottom diatoms in shallow waters are preeminently valuable to fisheries. Organic detritus from incoming streams and from shore drift makes excellent fertilizer for the growth of diatoms on the better lighted bottom areas along shore. Fishes breed in this shallow water and the young find excellent pasturage in the diatom-copepod association of the near-shore areas.

If one examines the diatomaceous earth from Maryland, California, Virginia, Japan, Spain, the Soviet Republic, or New Zealand, one finds diatoms that once belonged to the sea. Some of these fossil beds are vast. The one at Lompoc, Santa Barbara County, California, covers about twelve square miles and contains fourteen hundred feet of commercially pure diatoms in addition to three thousand feet of diatom-bearing strata which contain admixtures of clay or lime or sand or gravel. What is the source of these marine algae? Such areas were once under the sea and represent the accumulation through thousands of centuries of the siliceous valves of the diatom cells that grew there. The deposit at Lompoc is probably of late Pliocene or early Pleistocene age. It perhaps formed in a coastal bay by the repeated aggregation of diatoms on the surface of the ocean floated by their gelatinous envelopes and the subsequent massing in the bay by wind drift.

There are lesser fossil diatom beds of freshwater species occurring in New Jersey, New Hampshire, Alabama, Nevada, and Germany. It is generally conceded that algae are geologically among our oldest plants in spite of the fact that

fossil remains of many groups are unknown. (*See Chapter VIII.*) The fossil diatoms contain species now apparently extinct as well as other forms that are still common today. It is difficult to see how evolution can proceed much further in the amplification and extension of the magnificent structure that obtains in the siliceous shell of the diatom. The diatoms, even though present today in prodigious quantity both in sea and in fresh water, belong to an antiquity besides which Eden and the Pyramids and the Pharaohs are but yesterday. The economic uses of these ancient organisms will be discussed later.

Having taken a diatomaceous view of antiquity, let us return to modernity for a brief consideration of other forms of the sea phytoplankton. In warmer waters especially occur large numbers of "terrible" flagellated animal-plant organisms—the Dinophyceae—represented by *Ceratium*, *Peridinium*, *Gonyaulax*, and *Proceratium*. The cell wall, highly ornamented or not, usually consists of a number of angular plates fitting close together. Running around the cell is a well-marked groove, known as the horizontal furrow, connected to a pore. From the pore upward usually extends a short longitudinal furrow. From the pore arise two long flagella. The members of the Dinophyceae are usually yellow-brown in color.

Other plankton forms are illustrated by the beautiful, green, globular *Halosphaera;* the blue-green *Trichodesmium* which paradoxically gives the red color to the Red Sea; *Merismopedia; Chroococcus;* and *Gloeocapsa.*

The ocean then is a colossal ecological complex. It is salty, much of it is cold and dark and exerts enormous pressures on its inhabitants, the water is subject to wind and wave and current, and it is the largest unit of the earth. Its specific gravity is almost the same as that of protoplasm. It teems with vegetation or it may be barren as the Sahara, depending upon the time and place. Its plants and animals are nearly exclusively marine, may live at the surface or at more or less great depths, and vary almost infinitely in size, color, shape, structure, and habit. The genesis of such a population is the mass of marine algae: popularly the grass of the ocean, more exactly the primary food supply of the sea.

# CHAPTER VII

## ALGAE OF THE SOIL

MOSES records (Gen. 1:26) that the newly created man was given "dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth." Although we must admit this to be a very latitudinous grant of powers, it is exceedingly doubtful if the great Lawgiver consciously included the microorganisms of the soil. If he did, we can only say that until relatively recently man was entirely unaware of his vested suzerainty.

When you spade up the garden, resod your lawn, or plow a field, did you know you were dealing with a habitation of micro-population whose individuals outnumber all the people who have walked the earth since the beginning of time?

The microorganisms of the soil consist of bacteria, fungi, protozoa, and algae. A gram of well manured soil may contain 21,000,000,000 bacteria or 2,000,000 fungi or 1,000,000 algae or 500,000 protozoa. How many in an Illinois cornfield? In the state of Texas? Even Einstein with his fourth dimension must be mute at the answer.

After a rain whole fields of cultivated soils in plains and prairie and semi-arid regions may be practically covered with the balloon-like alga known as *Botrydium*. Garden soils often have considerable growths of *Microspora*, *Vaucheria*, and *Oscillatoria*. The growth of liverworts in greenhouses for long periods of time is often impossible because of infestations of the soil by blue-green algae. In every greenhouse flower pot one can usually find a mat of the velvet alga, *Vaucheria*. Large gelatinous masses of surface algae in temperate regions are often *Nostoc commune*. In more tropical regions species of blue-greens with copious peripheral mucilage may cover acres of ground. In fact algae are pretty universally distributed on

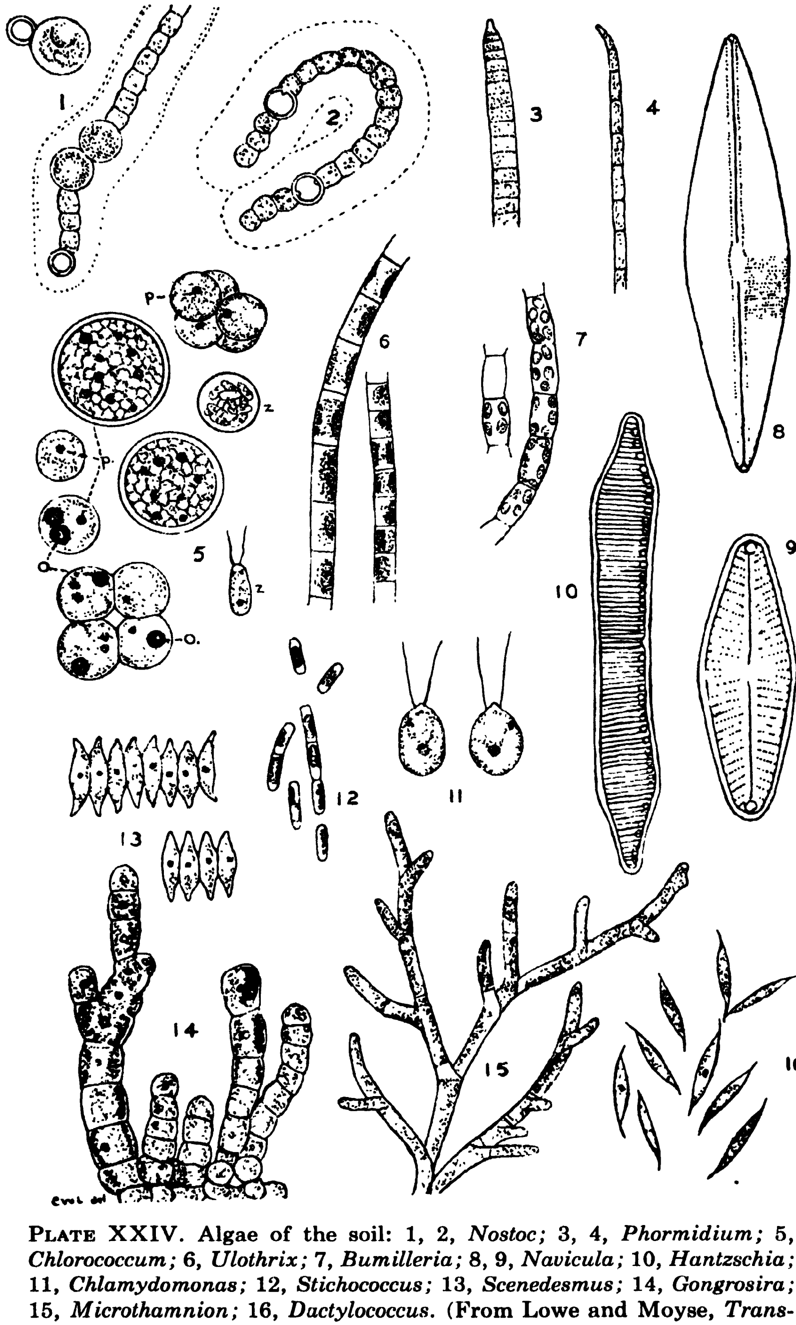



PLATE XXIV. Algae of the soil: 1, 2, *Nostoc;* 3, 4, *Phormidium;* 5, *Chlorococcum;* 6, *Ulothrix;* 7, *Bumilleria;* 8, 9, *Navicula;* 10, *Hantzschia;* 11, *Chlamydomonas;* 12, *Stichococcus;* 13, *Scenedesmus;* 14, *Gongrosira;* 15, *Microthamnion;* 16, *Dactylococcus.* (From Lowe and Moyse, *Transactions Royal Society of Canada.*)

the soil surface, and usually a little moisture and light are sufficient to secure an abundant growth.

Such growths of algae at the surface as well as at deeper depths, together with other microorganisms, must have a profound influence on the biology of soils. Of these soil organisms only the algae and the autotrophic bacteria can synthesize organic compounds from inorganic substances: the latter by chemosynthesis, using inorganic materials as sources of energy; and the former through photosynthesis in sunlight. Much less attention has been given to geophilous algae than either to their aquatic relatives or to soil bacteria and fungi. Their importance is, however, generally accepted and we may profitably discuss some of the facts about them.

The difficulties inherent in the study of soil algae have doubtless retarded our progress in more completely understanding them. It was for a time supposed that algae existed in soils only in the form of dormant spores. This conclusion was doubtless arrived at because of the apparent spontaneous development of algae upon moistening what seemed to be sterile soil. Many algae, as a matter of fact, occur at considerable depths in the soil in the vegetative state. It is necessary in many cases before soil algae may be studied and identified with certainty to isolate and grow them upon artificially prepared media. Sometimes this is a simple matter, but more often it is quite difficult.

Culturing soil algae varies all the way from merely improving the environment by better moisture, temperature, and light conditions to growing a single species free not only from other algae but also from bacteria as well. Since most algae are peripherally gelatinous, it requires special technique to rid the culture of the bacteria present in the almost ideal medium of sheathing mucilage. Actively growing cells, frequent transfers, and often vigorous shaking may fail to eventuate a bacteria-free growth of algae.

Using proper sterilizing precautions a given quantity of soil may be added to a flask or bottle containing a layer of sand, to which a so-called culture solution has been added.

The bottles are then set in medium light in a slanting position. Water lost by evaporation through cotton stoppers must be replaced. Algae usually begin to grow in about a week or two, and then transfers of single cells or filaments may be made to other solutions or to tubes of agar. It has been ascertained that nearly every alga has its slight variation in the composition of a culture solution for optimum growth, of which Kufferath has made an excellent summary. These culture solutions are fundamentally alike, however, and the following (Bristol) is representative of the more successful ones:

| | |
|---|---|
| $NaNO_3$ | 0.5 gram |
| $KH_2PO_4$ | 0.5 gram |
| $MgSO_4 \cdot 7H_2O$ | 0.15 gram |
| $CaCl_2$ | 0.05 gram |
| $NaCl_2$ | 0.05 gram |
| $FeCl_3$ | 0.005 gram |
| Distilled water | 1000 cc. |

Now if algae may grow at considerable depths in the soil, what of their light requirements? Probably most species of algae occur in the upper six inches of the soil, although diatoms and some blue-greens are found at depths of four to six feet. Occasional references to algae at depths of thirty to forty feet are doubtless accidents of temporary lodgment, due to excavations or unusual disturbances in the porosity of the ground. The algal population of most soils decreases exceedingly rapidly below the one-foot level. Russell estimates that in a gram of manured soil there may be as many as 1,000,000 algae, having a volume three times that of the bacteria. Such numbers of plants, even individually very small, three or four inches below the surface must live in complete darkness. What of their photosynthetic activities?

It has been known for years that certain algae may grow on organic media in complete darkness. One of the most interesting cases on record is that of a *Scenedesmus* (a green alga) which grew thus in darkness for eight years, using glucose and peptone as sources of carbon and nitrogen. When the alga was

removed to the light, photosynthesis began in five hours. Similar data for other green algae would appear to indicate their heterotrophic propensities. The evidence for heterotrophic nutrition among the blue-green algae is, however, not very conclusive.

Probably due to the fact that the presence of algae was known to build up the organic content of soil, numerous investigators became interested in the problem of ascertaining whether algae were able to fix atmospheric nitrogen. It will be recalled from an earlier discussion that although nitrogen is essential in protein synthesis the atmospheric source is not directly available to green plants. In spite of reports to the contrary, there is no *bona fide* evidence that bacteria-free cultures of algae are able to utilize the free nitrogen of the air. Bouilhac and Guistiniani found that on sand completely destitute of organic matter and nitrogen compounds a *mixture* of algae and bacteria not only developed normally on the sand but enriched it sufficiently for seed plants to grow. The capacity for *Azotobacter*, for example, to fix nitrogen is greatly enhanced by the presence of algae. The province then of nitrogen fixation remains apparently with the bacteria. Perhaps the relationship is a symbiotic one: the gelatinous sheaths of the algae are sources of carbohydrates for the bacteria and the latter provide nitrogen compounds for the algae.

No very definite data are available as to the distribution of algae in different kinds of soils, but a rather limited correlation is suspected. The physical properties of the soil will perhaps be considerably secondary to the mineral and water content. Mineral salts are used by soil algae in very dilute solutions, but many are absolutely essential. Besides water, carbon dioxide, oxygen, and nitrogen supply, the algae require salts of potassium, iron, magnesium, phosphorus, sulfur, calcium, and perhaps others. In uncultivated areas moist sandy soils stand first in algal productivity over bogs, heaths, and forests. Grass lands appear to be richer in algae than arable soils, although the latter have more blue-greens than uncultivated soils. The algal flora of acid and alkaline soils

is often quite dissimilar in spite of the fact that algae survive in a considerable range of hydrogen ion concentration. Well-manured soils may have a hundred times as much $CO_2$ as the air above them.

It was formerly supposed that soil algae were merely depauperate forms of aquatic organisms that had been transferred through the accidental agencies of wind, water, or animals. Most algologists are now convinced of a rather definite soil flora. Small forms of diatoms, for example, are not reduced aquatics, but rather their size has perhaps been a factor enabling them to survive. In soils of Britain, Bristol has definitely identified 24 species of blue-green algae, 20 diatoms, and 20 greens. These species had previously been subjected to artificial desiccation from four to twenty-six weeks. Some 75 genera and perhaps 200 species of soil algae are known, if we include the surface forms along with those at subsurface depths.

Soil algae may exist in extremely unfavorable moisture environments for very long periods in so-called resting stages or resting spores. Such spores were reported some years ago to be able to withstand complete desiccation for over seventy years. Later investigation showed, however, that the stored soils used in the experiment had at times been moistened. Very recently Lipman has reported the existence of spores of both green and blue-green algae in soils kept sealed 25 33 years and in bottled subsoil unopened for 65 years. Even more amazing is Lipman's record of single-celled green algae from adobe bricks from the interior of thick walls of a California mission from structures over 100 years old. Bristol records from English soils 9 species of blue-greens, 4 greens, and 1 diatom from resting cells stored for nearly forty years. *Nostoc* and *Nodularia* remained viable longer than any others. Coyle has recently listed 94 species of subterranean algae from Ohio soils.

Algae in almost incredible numbers are present in most soils and can apparently exist in subsoils in complete darkness. They doubtless aid in nitrogen fixation in symbiotic

relationship with bacteria. They are of the greatest importance in newly formed soils in adding organic matter through their photosynthetic activities. They may assimilate nitrates which later are slowly released, especially in uncropped soil. Aeration of roots of swamp plants is apparently aided by algae in utilizing the dissolved carbon dioxide and releasing oxygen. Those algae existing in complete darkness become consumers of soil energy and thus are really saprophytic.

## CHAPTER VIII

# ALGAE OF ICE AND SNOW

WE OFTEN hear about arctic and antarctic wastes of ice and snow, and of perpetually ice-capped mountain peaks and snow-filled alpine valleys. What manner of life is associated with the low temperatures of such places? In a previous chapter we have observed that certain algae live and grow in hot springs at temperatures as high as 80–84° C. At what *low* temperatures may algae exist? Our data are unfortunately meager, but let us examine them.

Green and red algae of the ocean may be found at depths of 200–300 feet in water whose temperature is considerably below that at the surface. Plankton forms of various species occur in cold springs and in alpine lakes and streams. Bright green, vigorous plants of *Cladophora*, *Rhizoclonium*, and *Vaucheria* may be obtained from under the ice in the latitude of Ohio (U. S. A.) practically all winter. The ubiquitous *Pleurococcus* found on tree trunks in temperate moist climates survives winters whose air temperatures may get as low as −20° to −40° C. Arctic and antarctic explorers, as well as alpine investigators, report numerous and rather extensive patches of red snow, yellow snow, green snow, and even black snow. These variously colored patches of snow are due largely to algae.

The flora of perpetual ice and snow has been referred to as "Cryoplankton." The plants are of course not free-floating and hence not properly referable to plankton only in so far as the similarity of genera and sometimes species. If we must have a double-barreled appellation, the term "Cryovegetation" of the Norwegian limnologist Ström seems applicable; or perhaps a simpler, more definitive word is "Cryoalgae."

Snow algae occur in both arctic and antarctic latitudes as well as in high altitudes of mountains of most countries. Some-

times the coloration due to these microscopic plants is very bright; in other cases it may be only faintly visible. The latter is more likely to be the case in soft snow where the algae are found 1 to 2 inches below the surface. Darwin observed many years ago that apparently bloody traces remain after walking over snow with subsurface algal forms. Even on the hard snow the plants are usually most prominent in the "troughs of the waves."

A word is necessary here regarding the actual temperature in which the snow algae grow. Red and yellow snow in particular are found in abundance only on surfaces where the snow is actually melting; that is, at temperatures near the freezing point. This then is not far different from the temperatures to which deep sea algae and the plankton of cold streams and lakes are subjected. It should be noted in this connection, however, that vegetative cells of *Dunaliella* were observed by Teodoresco to become quiescent only when the temperature of salt water was lowered to about $-20°$ C. The pigmented algae undoubtedly absorb considerable heat and in this way actually are factors in the thawing and melting of surface snow and ice. Even the subsurface algae receive the rays of heat that easily penetrate the upper centimeters of snow.

Most writers have emphasized the prevalence of fat compounds in snow algae as an "adaptation" against severe cold. It is not possible definitely to do more than call attention to the abundance of fat reserves in snow algae: to establish a causal relation between cold resistance and the presence of deposits of fats requires more evidence than is now available. When it is realized, as noted above, that the actively growing algae of snow and ice are not subjected to temperatures much below the freezing point, the matter of cold resistance ceases to be a striking phenomenon. At seasons of little or no sunlight, however, when temperatures become very low, the algae for the most part are in dormant stages or spores. Such spores, along with seeds and other dormant organs of flowering plants, are able to withstand almost incredible ranges in temperature and moisture content.

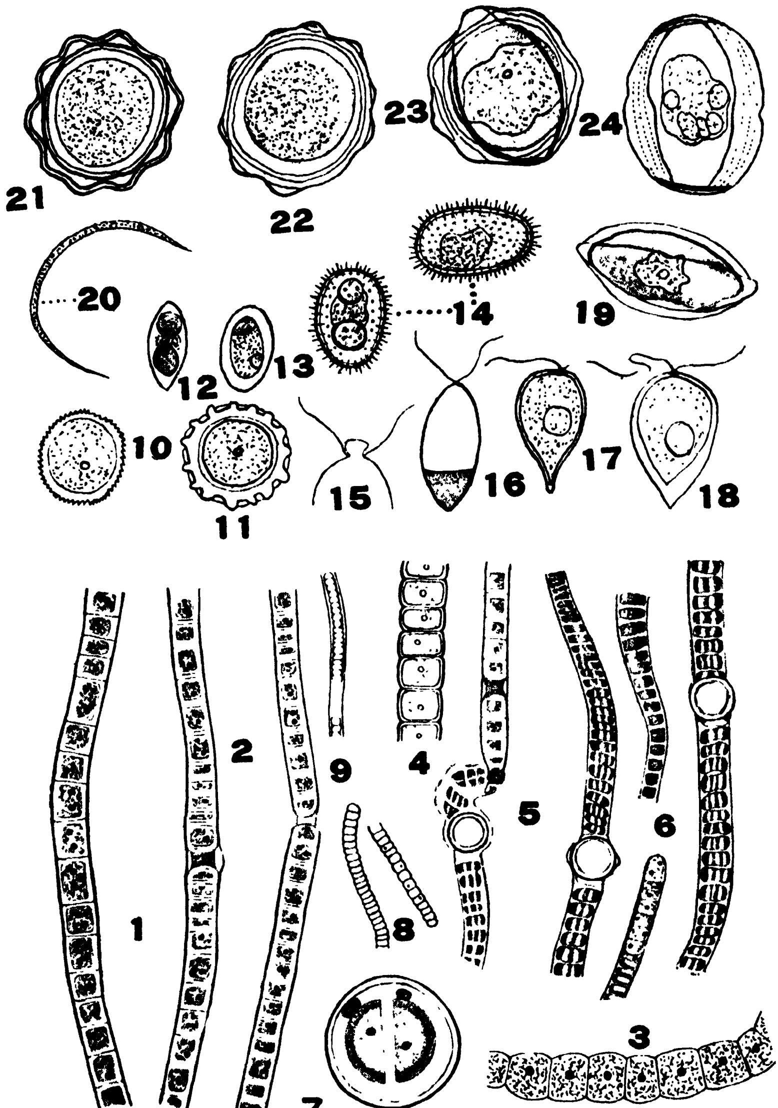



PLATE XXV. Algae of ice and snow: 1–6, *Prasiola;* 7, *Pleurococcus;* 8, 9, *Phormidium;* 10, 11, *Trochiscia;* 12–13, *Oocystis;* 14, *Lagerheimia;* 15–18, *Chlamydomonas;* 19, *Pteromonas;* 20, *Raphidonema;* 21–24, *Scotiella.* (From Fritsch.)

Red snow is probably the best known and most widely distributed of all the flora of perpetual ice and snow. Its color varies from delicate rose to blood-red or brick-red. The bloody traces remaining after walking on snow, referred to above, are due to the presence of algae containing a considerable amount of red pigment. The algae are largely species of *Chlamydomonas*, *Raphidonema*, and diatoms. There are also additional algae that might be considered accidental constituents of the red snow brought in from neighboring sea coasts and lake shores by winds and especially by birds like the penguins.

Fritsch has given the best description of yellow snow in his account of its distribution in the South Orkneys (latitude 61 S). The color varies from pale yellow to bright yellow. The algae are seen during the "summer" season and are doubtfully visible at other seasons due to the almost incessant drifting of the snow. Yellow patches of supposed algae are oftentimes nothing more than penguin manure. The yellow snow may apparently grow in patches near red snow, but the two are rarely if ever in mixed associations. The algal forms of yellow snow are more numerous than those of red snow and are represented by *Protoderma*, *Chlorosphaera*, and *Scotiella* as well as occasional species of *Ulothrix*, *Oedogonium*, *Pleurococcus*, and *Nostoc*.

Green snow has been seen in the Alps and in arctic regions. It is made up largely of green algae, such as *Chlamydomonas nivalis* and *Ankistrodesmus* as well as a few blue-greens. Brown snow is perhaps essentially mineral in composition although a few desmids (like *Mesotaenium*), diatoms, and blue-greens are common. The algae responsible for the black snow of high mountains, such as those in Switzerland and those of the Tatria, are largely *Scotiella nivalis* and *Raphidonema*.

The presence of plankton algae *under* great thicknesses of ice has been known for a long time, and the quantity is perhaps much greater than we think, particularly if sufficient light is available. The subsistence of the Eskimo and other inhabitants of polar regions on what appears to be a purely meat diet is not so strange after all when one realizes that the animals,

in the ultimate analysis, depend upon the algae not only for basic foods but also for certain amino acids, vitamins, and perhaps other chemical compounds. Perkins of the Byrd Antarctica Expedition 1933 35 reports several types of diatoms along with copepods and foraminifera at depths of 800 ft. or more in the Bay of Whales. During the height of the antarctic summer diatoms seem to be unbelievably abundant

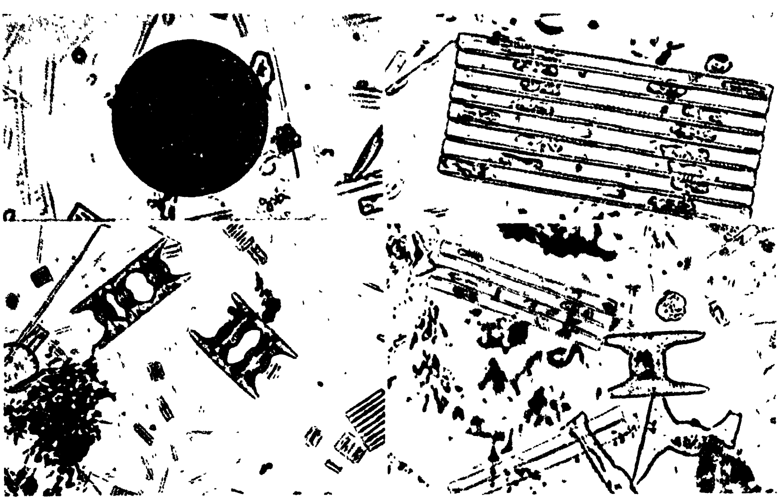


PLATE XXVI. Glimpses through a microscope: diatoms from Antarctica. (From Perkins in *Educational Focus*.)

in the upper surfaces of the water. As winter with its accompanying darkness sets in, the diatoms die of starvation, and the animals must then depend on algal remains, suspended organic matter, and each other for their food supply.

We learn then that even snow and ice have characteristic algal floras. The supposedly low temperatures to which these snow algae are exposed turns out to be not so unusual after all, particularly when they are growing. During the growing season—that is, summer—the algae occur in melting snow and ice at a temperature near the freezing point. It is the survival of the dormant cells of these algae during excessively cold periods that is difficult to explain. The presence of an

excess of fat in the cells can scarcely be shown to explain their resistance to cold. The algae give color to the snow, and there is, depending upon the kind of plants present, yellow, red, brown, green, and even black snow. The algae absorb considerable quantities of heat rays which further the melting of the snow appreciably.

## CHAPTER IX

# ALGAE OF BIZARRE ABODES*

IN PREVIOUS chapters we have seen that algae grow in many and diverse habitats. They are found in fresh and in salt water, in mountain torrents and quiet pools, on the surface of the soil and at considerable depths, on ice and on snow, from 300 feet below sea level to alpine heights, and from the equator to the poles. Perhaps it should not be surprising that algae live and reproduce in a multiplicity of environments, although the characteristics of protoplasm that permit survival under such extremes are well-nigh inexplicable.

Algae are also more or less intimately associated with numerous other living organisms, both plant and animal. An alga, in addition to the various habitats just enumerated, may live in or on another plant; or it may live in or on an animal. A short list of such animate "hosts" includes bacteria, fungi, liverworts, cycads, magnolias, oaks, tea plants, water-fleas, worms, sponges, cockroaches, guinea pigs, ducks and chickens, bears, horses, cattle, sheep, goats, hogs and even you and me. Truly there are agencies even outside politics that make for "strange bedfellows."

Many species of algae are free-floating and constitute the so-called phytoplankton, or plankton algae. The aquatic forms, exclusive of the plankton, may be roughly termed sedentary or attached. Such plants may grow on almost any conceivable object or substrate: a reed or a rush or some other seed plant, an alga, an animal, a rock or a stone, a dock or a boat or a ship, a shell, the bottom of a lake or the bed of a stream, a log or a stick. The algae may be attached by special holdfast cells or by stalks and other forms of jelly-like material.

* Appeared essentially in *Scientific Monthly* for June, 1935.

Every one has seen long strands of *Cladophora* in running water; bright green coatings of *Ulothrix* and *Stigeoclonium* on stones of lake margins; slippery accumulations of *Fucus* on rocky seashores; and blue-green blobs of *Rivularia* on sticks and logs in quiet water. Some forms, like *Cladophora* and *Rhizoclonium*, are perennials and may be seen nearly any time of the year. Most of the attached algae, however, are abundant only at certain definite and rather short periods of time: *Ulothrix* in early spring and *Rivularia* in late summer, for example.

The particular object to which attachment is made appears to bear little or no relation to any specific alga. The greatest factor is undoubtedly proximity to the algae at the time of spore formation. Rough surfaces with small interstices are better sources of lodgment than smooth ones. In fact, the germinating spores of some algae, like *Oedogonium* or *Bulbochaete*, make rather imperfect holdfasts or none at all in smooth glass vessels. Discarded and untenanted snail shells of the rougher sort furnish ideal lodgment for *Cladophora* and *Stigeoclonium* spores which upon germination and growth give the appearance of "life anew" to such gastropodous castaways. Many algae, particularly the larger marine forms, grow on stones and rocks and are called lithophytes.

Partially or nearly submerged stones, sticks and logs may be covered by adhesions of gelatinous material containing in particular blue-greens and diatoms. *Nostoc*, *Cylindrospermum* and *Oscillatoria* may lie very close to the surface of the substrate; *Gomphonema* and *Navicula* may produce ever-lengthening stalks of mucus that supports the algal cells at some distance from the rock or stone.

Many of the algae discussed above become planktonic when the warm water dissolves the supporting mucilage. Great quantities of diatoms loosened at one time by a sudden increase in water temperature often form "pulses" in streams. Similar "blooms" develop in lakes and ponds with prodigious rapidity after germination of spores in the bottom mud and rise of the young plants to the surface of the water.

Algae attached to other plants and growing there are re-

ferred to as epiphytes. They should not be confused with the colorless parasites which depend upon their hosts for sustenance. Among seed plants we are familiar with epiphytic mistletoe, air plants, and tropical orchids. Many kinds of algae, such as *Aphanochaete*, *Bulbochaete*, *Stipitococcus*, or *Cocconeis*, may grow upon other algae like *Vaucheria*, *Cladophora*, or *Mougeotia*. In aquatic situations the leaf blades, leaf sheaths, and stems of practically all macrophytes serve as objects of attachment for algae. Cattails and some smartweeds rarely have abundant algal epiphytes, and it is quite possible that there are degrees of epiphytism among different plants.

It is well known that the peripheral parts of most algae are quite gelatinous. The slipperiness and sliminess of filaments of *Spirogyra;* the colonial matrix of *Volvox*, *Microcystis*, and *Tetraspora;* and the enveloping sheaths of *Lyngbya* and *Scytonema* are familiar to all. These mucilaginous coats are excellent habitats for bacteria. In most aquatic forms the association is probably quite accidental, and during vegetative growth the algae and bacteria may bear no relation except as space partners. In soil algae, however, the two members may be mutually helpful in nitrogen fixation. Mass accumulations of algae are doubtless hastened in their decomposition by associated bacteria of decay. Bacteria in the sheaths and coats of many algae are so nearly ever-present that it is practically impossible to grow absolutely pure cultures of some species. Czurda (University of Prague) has been able to get filaments even of such algae as *Spirogyra* free from bacteria by frequent shakings of vigorously growing plants in distilled water.

The non-aquatic epiphyte is perhaps more common to most of us. *Pleurococcus* (*Protococcus*) has been known for years as a name for the greenish incrustation on many tree trunks. It usually occurs on the less lighted or sometimes leeward side of the tree, and rarely grows in latitudes with an annual rainfall of less than twenty inches. It is more common on some trees than others, and this may be due to differences in rough-

ness of bark, humidity of the air, or age of the tree. *Trentepohlia* and *Prasiola* are also conspicuous members of what one might call aerial algae: those growing on barks of trees as well as on woodwork, masonry, stones, and cliffs not submerged. Aerial algae are thought to require an atmosphere of rather high humidity, even though the area may be extremely localized.

*Pleurococcus* seems actually to require very little water and so thrives in air of ordinary moisture content. It is characteristic of such algae that they are able to withstand long periods of desiccation without any appreciable injury to the vegetative cells. When moisture becomes available, the plants show rapid increase in greenness and vegetative activity. Apparently the cells are practically impermeable to water during these droughts, and Fritsch suggests that they are then in a state of "paralysis." Their protoplasts contain no large vacuoles, and the protoplasm survives without the customary water supply. Whatever the explanation of such remarkable resistance to desiccation, it is quite evident that something besides visible structural modification is fundamental.

In discussing aerial algae one finds it difficult exactly to delimit and classify. Many observers in tropical regions have been impressed with the prodigious abundance of aerial and subaerial algae growing on every stone, tree trunk, wall and roof, as well as on the ground. It has even been facetiously remarked that algae are found on some of the more sedentary brethren among the natives, but the writer has not verified such observation. It is true that in regions of excessive rainfall algal mats may be seen growing on almost any conceivable object. The algae are usually dark green rather than light green in color, and the blue-greens loom large in the composition of the flora. Colors vary all the way from bright blue to dark blue-green or nearly black. *Trentepohlia* along with a few other genera of green algae is very abundant, but it is usually some shade of orange-red unless growing in shady places.

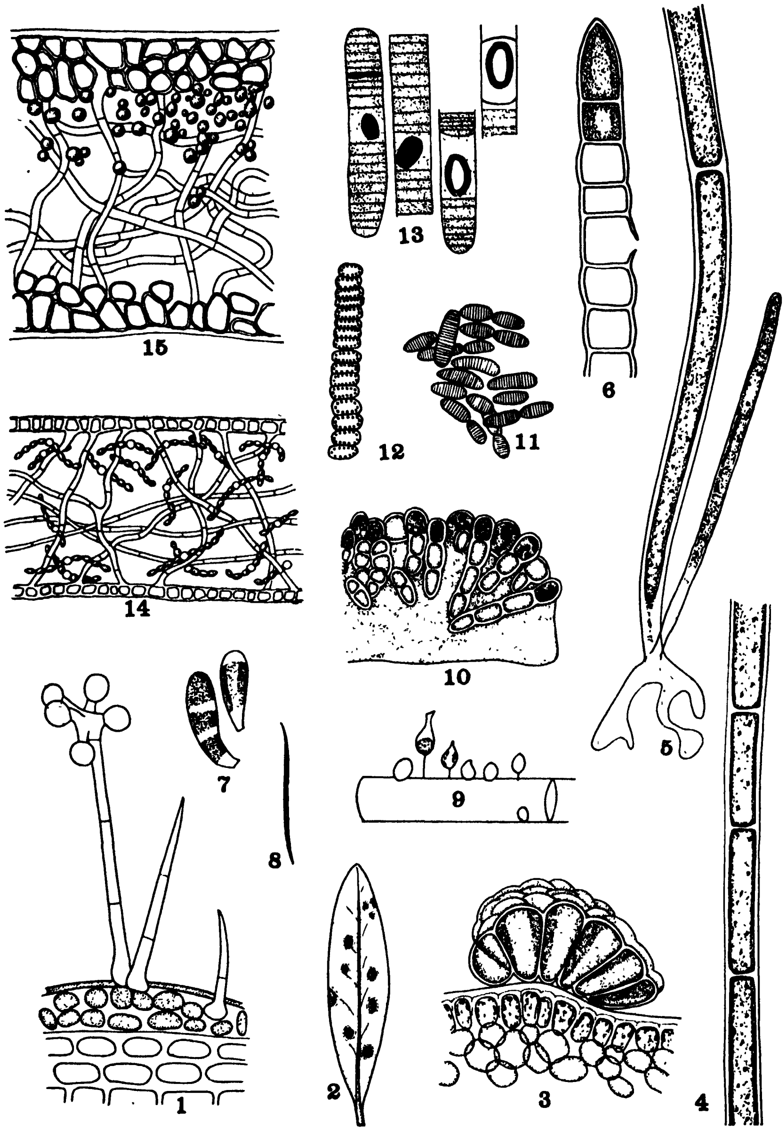



PLATE XXVII. Algae that grow in unusual places: 1, Part of a section of Rhododendron leaf showing *Cephaleuros* with protruding hairs and sporangial filaments (shaded cells are within the leaf); 2, Rhododendron leaf showing superficial view of patches of *Cephaleuros;* 3, epiphytic *Dermocarpa;* 4–6, *Basicladia* from backs of turtles; 7, *Characiopsis* from Crustacean appendages; 8, *Dactylococcopsis* from a bear; 9, *Stipitococcus,*

Not easily separable from the above are the algae which grow on the leaves of other plants: the so-called epiphyllous algae. They do not differ materially from bark epiphytes and other aerial forms. They apparently suffer little from desiccation because of the high humidity to which they are nearly continuously subjected. Some forms grow in intense light, while others are found in considerable shade. The number of species of epiphyllous algae is probably not large because the same plant may occur on almost innumerable hosts. The number of individuals, however, is doubtless equal or perhaps superior to that of any other group of plants in the tropics, with the exception of the bacteria.

There are various degrees of epiphyllism from the casual epiphyte to the real parasite. Most epiphyllous forms are disk-like, subcuticular, or merely place epiphytes. There are, however, a few genera that seem to be restricted to localized leaf areas. One of the most interesting is Palm's *Stomatochroon* which grows in the stomatal cavity of the leaf and is apparently anchored there by a lobed holdfast. The alga consists of a few cells, enters the cavity through the stoma, and is found on a wide variety of host plants, both cultivated and wild. It is perhaps the most widely distributed epiphyllous alga of the tropics. Rare in virgin forests of dense shade, it grows on open, sunny weed and bush vegetation of waste and fallow land, on low-growing secondary jungle, on pastures, and on garden and orchard plants. The aerial parts of *Stomatochroon* are golden-yellow to intense purple or brown, due to a richness of hematochrome in the cells. The basal cell is curiously enough vivid green and devoid of hematochrome.

---

epiphytic on filamentous algae; 10, *Cyanoderma*, from hair of ai, the three-toed sloth; 11, *Simonsiella* from man, horse, cow; 12, *Anabaeniolum* from man and guinea pig; 13, *Oscillospira* from deer and tadpoles; 14, section through the lichen, *Leptogium*, showing algal filaments (shaded) among fungal hyphae; 15, section through the lichen, *Peltigera*, showing single-celled algae (shaded) among fungal hyphae. (3, after Bornet and Thuret; 8, after Rosenvinge; 10, after Weber-van Bosse; 11–13, after Langeron; 14, after Schneider; 15, diagram by Celeste Taft from portion of camera lucida drawing by John Wolfe.)

Passage through the stomata in the case of *Stomatochroon* seems to be merely a matter of growth. It has been reported that amoeboid cells are responsible for the entry of species of *Chlorochytrium* and *Synchytrium* into leaves. *Cephaleuros* gains adit through cuticular and epidermal lesion by zoospore. When the algae are merely surface epiphytes, no apparent injury occurs to the host. Complete covering of areas of the leaf perhaps prevents the penetration of rays of light of certain wave-lengths, but the data are insufficient to draw any inferences. It is when such algae are subcuticular and subepidermal that pathogenicity becomes evident.

*Stomatochroon* may cause coppery or yellowish-red discolorations of the leaves of the host. True parasitism, or at least pathogenicity, however, is shown by the nearly ubiquitous *Cephaleuros* of tropical and subtropical regions. It grows in Florida, according to Wolf, on grapefruit, sweet lemon, Cuban shaddock, tea, magnolia, loquat, avocado, Spanish jasmine, tangerine, temple orange, cinnamon, fringe tree, shining privet, bay, and coral berry. The leaves are usually the parts infected, although the alga may occur on both twigs and fruits. It is sufficiently important in India on tea to be locally known as "red rust."

*Cephaleuros* normally causes velvety reddish-brown to orange colored cushion-like patches. If the epidermis is smooth, it may be found on both sides of the leaf; if the leaf is hairy on the lower surface, the alga appears on the upper side. It may be purely superficial, it may grow between the cuticle and the epidermis, or it may extend between adjacent epidermal cells into the chlorenchyma. The vegetative portions of the plant then may be strictly endophytic.

On the magnolia such infection is not noticeable till autumn when the leaves are about five months old. The algal thalli enlarge during the winter, and just prior to the rainy season —eight months after infection—both stalked and sessile sporangia appear. The plant continues to grow, and both sporangia and zoospores are produced throughout the summer, thus spreading the infection. Water and mineral salts are

taken from the host by the *Cephaleuros* thalli. Leaf cells adjacent to the alga die without modification in most plants, but in a few, cork formation is initiated. The algal parasite is usually controlled by defoliation, by fungicides and by the cultivation of vigorous plants.

Some groups of algae live almost entirely within other plants and are known as endophytes. Most of them are perhaps merely space-endophytes; that is, occupying the intercellular cavities only. Species of *Entocladia* may grow within the wall layers of other algae, like *Rhizoclonium*. A species of *Chlorochytrium* inhabits duckweeds, hornwort, elodea, and some mosses; an *Anabaena* lives in *Azolla;* and a *Nostoc* is found inside the thalli of the liverwort *Anthoceros*. Another species of *Nostoc* grows in the root tubercles of a cycad.

A most interesting group of algae, made up of blue-greens and greens, belongs to the algal constituents of lichens. A lichen is generally considered to be a mutual association of an alga and a fungus, perhaps symbiotic, perhaps commensal. The fact that one of the associates is holophytic, while the other is not, led to the early conclusion that the two are mutually dependent and beneficial: the alga furnishing carbohydrates through photosynthesis and the fungus offering protection and an added water supply. Perhaps the most remarkable thing about lichens is their ability to withstand extreme desiccation.

Most of the algal constituents of lichens are not aquatic and when free from the fungus grow in moist and shady places as epiphytes or aerial forms on stones and walls and tree trunks. Among the blue-greens associated with lichens are *Chroococcus*, *Microcystis*, *Gloeocapsa*, *Nostoc*, *Scytonema*, *Stigonema* and *Rivularia*. Of the greens there occur *Pleurococcus*, *Chlorella*, *Coccobotrys*, *Coccomyxa*, *Urococcus*, *Palmella*, *Gloeocystis*, *Trentepohlia*, *Cladophora*, *Cephaleuros*, *Phycopeltis* and *Prasiola*. The fungi are largely Ascomycetes (sac fungi).

Algae may also be epizoic. Common examples are *Synedra* on copepods, *Characiopsis* on rotifers, and *Characium* on

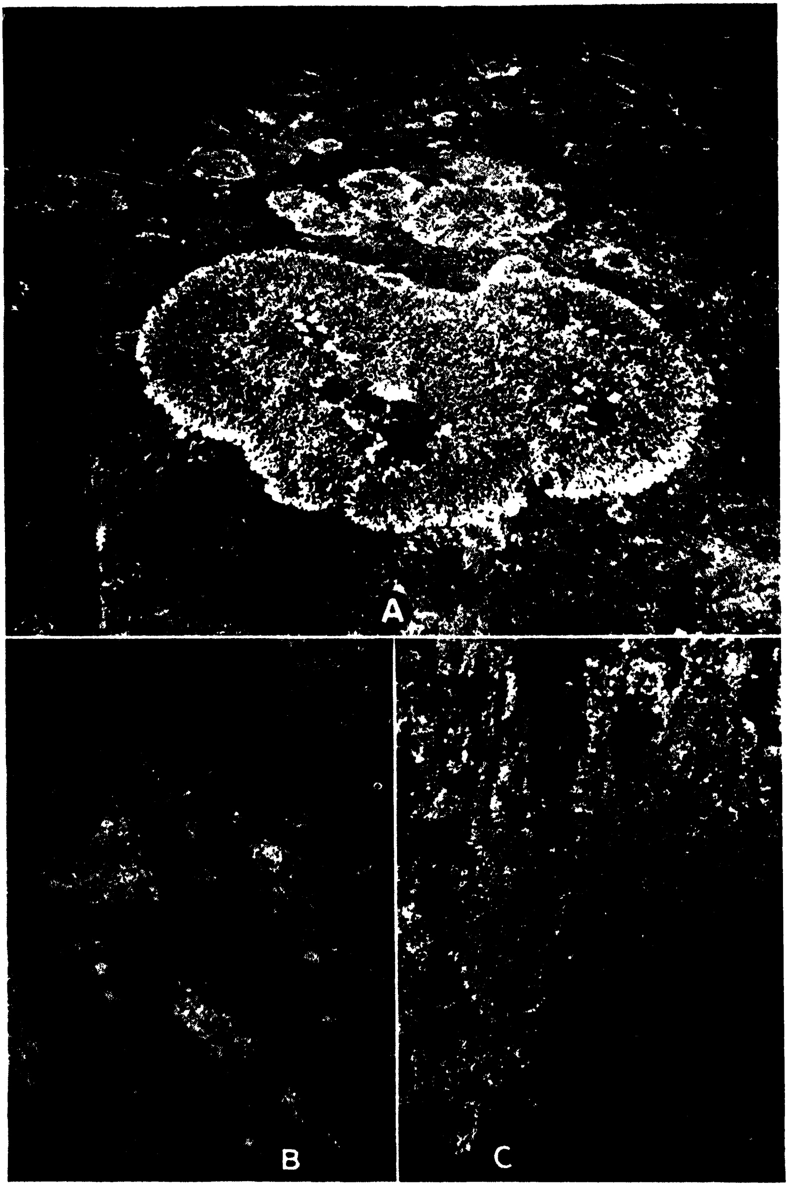



PLATE XXVIII. Lichens: A, *Parmelia* on rock; B, *Gyrophora*, the rock tripe; C, *Parmelia*, on bark of tree. (A, B, photograph by Gordon Crowl; C, photograph by John Wolfe.)

certain crustacea. One species of *Characiopsis*, for example, is often found only on the tail of a small crustacean (*Branchipus*), while another and related epiphyte may be confined to the forward appendages of the same animal. This is certainly a case of ecological definitiveness with a vengeance. Algae are found, in addition, on protozoa, amphipods, water fleas, fishes, and turtles.

In summer one can easily get a sizable collection of the attached *Basicladia* (freshwater *Chaetomorpha*) by catching turtles conveniently carrying on their backs firmly anchored tufts of the green filaments. In fact *Basicladia* is one of the few algae that may be identified at a distance, "on the go," and by the "company it keeps." Several species of blue-greens, reds and greens are associated with sponges; in some cases this relationship seems to be symbiotic and will be mentioned later.

We crossword puzzle devotees have repeatedly forgotten a "two-letter word for the three-toed sloth." The animal is the ai and it carries on the shaft scales of its long outer hairs a multitude of individuals of the tiny red *Cyanoderma*, often accompanied by the green *Trichophilus*.

Perhaps the strangest algae of all are the endozoic forms. Man has long known that his digestive tract, as well as that of many another animal, contains a regular menagerie of bacteria and protozoa— organisms sometimes annoying and destructive but usually harmless and perhaps even necessary to comfort and gastronomic happiness. It is only recently, however, that the algae have been found as a part of this strange assembly. Animals aquatic and terrestrial, vertebrate as well as invertebrate, great and small, are now thought to be hosts to certain species of algae, not only in their stomachic and intestinal tracts but even sometimes in the body cavity itself.

The earliest known endozoic algae were probably the "Zoochlorellae" found growing in apparently symbiotic relationship with infusoria (*Paramecium*, *Stentor*) and especially the green *Hydra*. *Chlorella* occurs in the cells of *Hydra viridis;*

*Carteria* is associated with the worm *Convoluta;* and numerous species belonging to such genera as *Gongrosira*, *Spongocladia*, *Struvea*, *Thamnoclonium*, *Aphanocapsa*, *Phormidium*, and *Lyngbya* are intimately associated with sponges. A species of *Aphanocapsa* (*A. raspaigellae*) occurs in the cells of sponges growing at depths of from 10 to 25 meters. *Chlorochytrium* is reported to grow in the skin of the carp.

Certain animals, including protozoa, coelenterates, and flatworms, apparently may live without ordinary feeding because they harbor green algae. In such cases the animal dies when subjected to darkness. Perhaps the animals receive carbohydrates and oxygen from the photosynthesis of the algae which in turn profit by the nitrogen compounds and carbon dioxide from animal respiration. Some attempt has been made to utilize this relationship in keeping tissue cells *in vitro* alive and healthy, a sort of artificial symbiosis. It may be that such plant cells utilize the products of tissue respiration *in vitro* and that increased and healthier growths of tissue result from the association with the algae.

It was just about a century ago that Valentin and Farre noted blue-green-like algae from the intestine of the human species. Most of the work on endozoic algae, particularly of vertebrates, has been done, however, during the last two decades. The hosts are numerous. The algae, though apparently strictly parasitic or saprophytic within the animal digestive tract, may become holophytic when removed to a lighted environment. It has been occasionally objected that these internal inhabitants are merely chance visitors from food eaten by the host. The evidence seems clear, however, that actual attachment is made with the intestinal wall and the algae live and grow endozoically for considerable periods of time.

A partial listing may suffice to show the ramifications of the ecological propensities of vertebrate-inhabiting algae. *Oscillospira* has been reported from guinea pigs, tadpoles, and deer; *Simonsiella* from man, horse, cow, pig, goat, sheep, and fowl; *Alysiella* (which by the way looks more like a filamentous

diatom than a blue-green) from the pharynx of a hen and from the intestine of horse, pig, sheep, and goat; *Anabaeniolum* from guinea pig, man, and the rabbit-like rodent agouti. It should be noted that for the present at least all such endozoic algae are classified with the blue-greens.

The tables may be turned in these queer relationships when the algae become hosts. Vorticellae are very numerous on the blue-green *Anabaena* at certain stages of its life history. Species of rotifers grow within the colonies of *Volvox* and *Coelosphaerium* and inside the cells of *Vaucheria* and *Cladophora*. Many fungal parasites, particularly the Chytrids, infest *Spirogyra*, *Oedogonium*, *Mougeotia* and numerous other algae.

It has been known for a long time that living spores of algae and fungi may be blown considerable distances by winds, and thus for intervals of time have their "abode" in the air. Birds in their long flights from one continent to another undoubtedly carry algal spores on their feet and legs from lake to lake and pond to pond. One would naturally expect more microorganisms in the air over tropical and temperate zones than in polar regions. Colonel Lindbergh in his aerial exploration near the Arctic Circle in the summer of 1933 in his *Tingmissartog* collected from the air some samples of unicellular algae, fragments of filamentous algae, and diatoms. Many such forms are of course lifeless.

When one tries to explain the habits and behavior of one's fellow man, he is often driven to mutter that there is no accounting for tastes. It is equally difficult, on the basis of our present knowledge, to account with any adequacy for the various associations in which algae grow. Some habitats seem natural and call for very little comment; others appear unusually heterodox and bizarre. It is doubtful if any other group of organisms on earth live and grow in more diversified and numerous environments than do the algae.

## Chapter X

# ALGAE OF THE PAST

It has been said that speculative man has always been interested—save when hungry or in love or in danger—in three questions: Where did I come from? Where am I now? What is to become of me? The answers to these questions (fortunately for the author) do not lie within the compass of this little book. The queries point significantly, however, to the theme of the chapter.

Estimates vary considerably, but it now seems fairly certain that this old earth of ours has been hurtling through space for two or three billion years. How much are two or three billions? We might, of course, indicate that a billion is merely a thousand millions, the cube of a thousand, or ten raised to the sixth power. About the best our minds can do, however, is to admit that a two-billion-year-old earth is quite an old planet.

How are such almost inconceivably high estimates of the earth's age arrived at? The method has been called the radioactive time-clock process. Some rocks, for example, might be termed geologic chronometers for they contain radioactive elements like uranium, radium, and thorium. Such elements discharge particles of matter from their atoms and so become different substances. Uranium becomes radium by getting rid of some atoms of helium and several electrons. Radium further discharges radium emanations (a gas) and, after losing some atoms of helium, becomes lead. The helium and lead undergo no further change: the geologic clock has stopped and cannot again be wound. Now it is known that each of these chemical changes proceeds at a very definite rate which is not altered by ordinary natural phenomena. So in a rock including uranium, as for example the uraninite-containing rocks from near

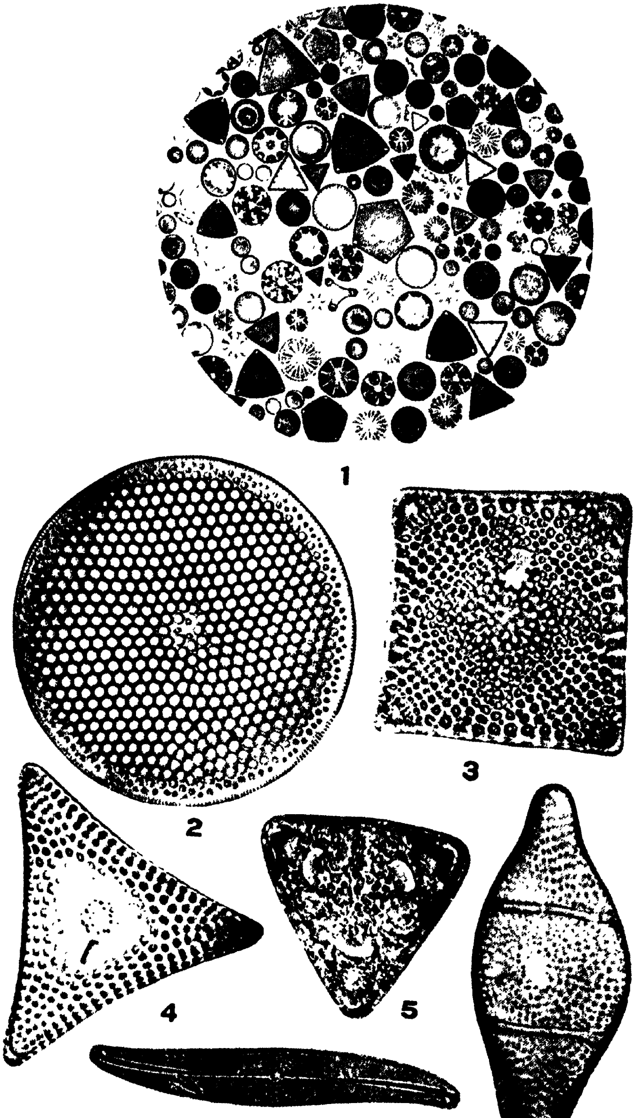



PLATE XXIX. Algae of the past: fossil diatoms: 1, group of fossil marine diatoms from Hungary (from Mann); 2, *Coscinodiscus;* 3, 4, *Biddulphia;* 5, *Entogonia;* 6, *Gyrosigma;* 7, *Anaulus.* (2–7, from Boyer, *Contributions from the Biological and Microscopical Section of The Academy of Natural Sciences of Philadelphia.*)

Winnipeg, Canada, the ratio of uranium to lead is a measure of the age of the rock.

We have thus inquired a little into the beginnings of things and glimpsed somewhat the great antiquity of the earth. Were algae present two or three billion years ago? Obviously not, for the earth's temperature at that time was doubtless too high and its oxygen supply too low. Perhaps a better statement is that two or three billion years ago algae did not exist at all; in fact, life of any kind as we know it now could not have endured. Even H. G. Wells in his most fanciful moments has never discussed such a possibility.

As to the time and place and manner of the origin of life upon the earth, no data are available. There are several interesting conjectures. The first living organisms must have been composed of relatively few molecules. Perhaps early life was comparable to present-day viruses or bacteriophages. Non-green plants such as our sulphur and iron bacteria may have been the progenitors of the fauna and flora known today. This seems plausible because of the early scarcity of oxygen and carbon. Such organisms of necessity oxidized without atmospheric oxygen other compounds besides carbon. At any rate life on the earth must soon have been associated—at least after the atmosphere became what it is today—with simply constructed organisms containing chlorophyll. This substance, you will recall from Chapter II, is necessary for the making of energy-containing foods from the inorganic compounds of air and soil and water.

Organisms simple in structure and able to synthesize chlorophyll bring us immediately to the algae. We do not know, and never can know, what the first algae looked like. Out of some primeval ancestor, however, emerged at a very early date an alga something like *Chlamydomonas:* single celled, motile, green, and capable of prolonged dormancy. From such a plant may have developed all the various kinds of algae (and even other organisms) known to the world today.

If we are unable to get back to remote antiquity to study algae, let us go into the past as far as we can. It will be sur-

prising how far back we may go and what we may find. On the basis of evidence found in the rocks geologists divide earth history into periods or eras or ages. Other than the uranium-radium-lead time-clock mentioned above, perhaps the two most important methods of interpreting geologic time are (a) the rate of land erosion and deposition and (b) the rate at

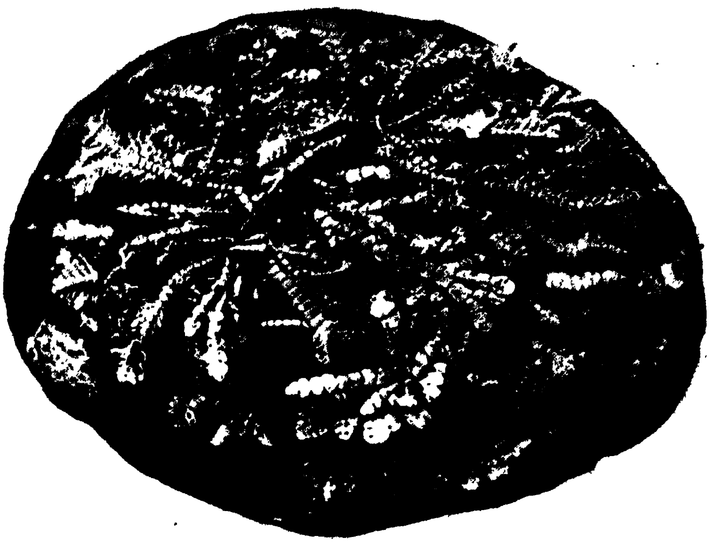


PLATE XXX. Coralline algae growing on sea shells. (From the Smithsonian Scientific Series.)

which sodium chloride has been derived from the land and has accumulated in the oceans. By such methods the geologists erect a time scale, such as is shown in tabular form on the next page.

The evidence for the plants and animals characteristic of each period is secured from fossils. A fossil may be defined as a plant or an animal, or a part of such organic body, found in rock or other earthy material, capable apparently of long-time preservation. How have the plants and animals of the past become fossils? There are several ways.

A part of a plant, such as a leaf, may be inclosed in sand or

TABLE 3. THE GEOLOGICAL TIME TABLE (*Adapted from Roy, Field Museum of Natural History, Geol. Leaflet 9*)

| Era | Period | | Time Scale | Characteristic Life |
|---|---|---|---|---|
| Psychozoic | Recent | | 25,000 | Age of Man |
| Cenozoic | Quar. | Pleistocene | 1,500,000 | |
| | Tertiary | Pliocene | 9,000,000 | Age of Mammals and Modern Flowering Plants |
| | | Miocene | 23,000,000 | |
| | | Oligocene | 39,000,000 | |
| | | Eocene | 65,000,000 | |
| Mesozoic | Cretaceous | | 150,000,000 | Age of Reptiles |
| | Jurassic | | 195,000,000 | |
| | Triassic | | 240,000,000 | |
| Paleozoic | Permian | | 280,000,000 | Age of Amphibians and Ancient Floras |
| | Pennsylvanian | | 330,000,000 | |
| | Mississippian | | 370,000,000 | Age of Fishes |
| | Devonian | | 420,000,000 | |
| | Silurian | | 460,000,000 | Age of Higher Shelled Invertebrates |
| | Ordovician | | 590,000,000 | |
| | Cambrian | | 700,000,000 | |
| Proterozoic | Algonkian, etc. | | 1,000,000,000 | Age of Primitive Invertebrates and Algae |
| Archaeozoic | Loganian, etc. | | 1,500,000,000 to 2,000,000,000 | Dawn of Unicel-lular Life Algal Forms Reported |

clay or a limy ooze that becomes limestone. Years later the solid sandstone, clay, or limestone may reveal (upon cracking or splitting) the leaf as a thin film of carbon-like matter or as a nearly perfectly preserved specimen. This is known as an inclusion. More often it is the impression of the leaf or other plant part on the earthy matter, rather than the actual remains, that furnishes the characteristics of the structure so fossilized. Actual specimens of both plants and animals may be perfectly preserved in amber, a fossil resin from some ancient pine or spruce or arbor vitae.

As far as the algae are concerned, however, fossil records other than those above are much more important, since such plants are and apparently always have been predominantly aquatic. Lime or silica in waters of hot springs may become precipitated on plants as incrustations, completely enveloping the delicate plant parts. Such incrustations appear on well-preserved specimens of *Chara* and marine algae. Most important of all however are the fossils known as infiltrations. An alga, such as a blue-green or one of the so-called seaweeds, slowly decays in water containing quantities of silica or lime or magnesia in solution. As the process of decay proceeds, mineral matter replaces the plant bit by bit until finally it is completely "mineralized." Sometimes the replacement is so thorough that even the most delicate ornamentations of cell walls are perfectly preserved.

It now seems fairly certain that algae were present and presumably wide-spread in pre-Cambrian times (pre-Cambrian is a term used sometimes to include any or all of the millions of years before the Paleozoic). It is thought that the extensive deposits of lime found in the sedimentary rocks of these early geologic eras were produced by algae similar to our present blue-greens. Perhaps a better idea of what may have occurred is to be gleaned from a reference to some more recent calcareous deposits or formations. Around the basins of many of our hot springs may be seen brightly colored deposits of travertine and sinter, due in numerous instances to

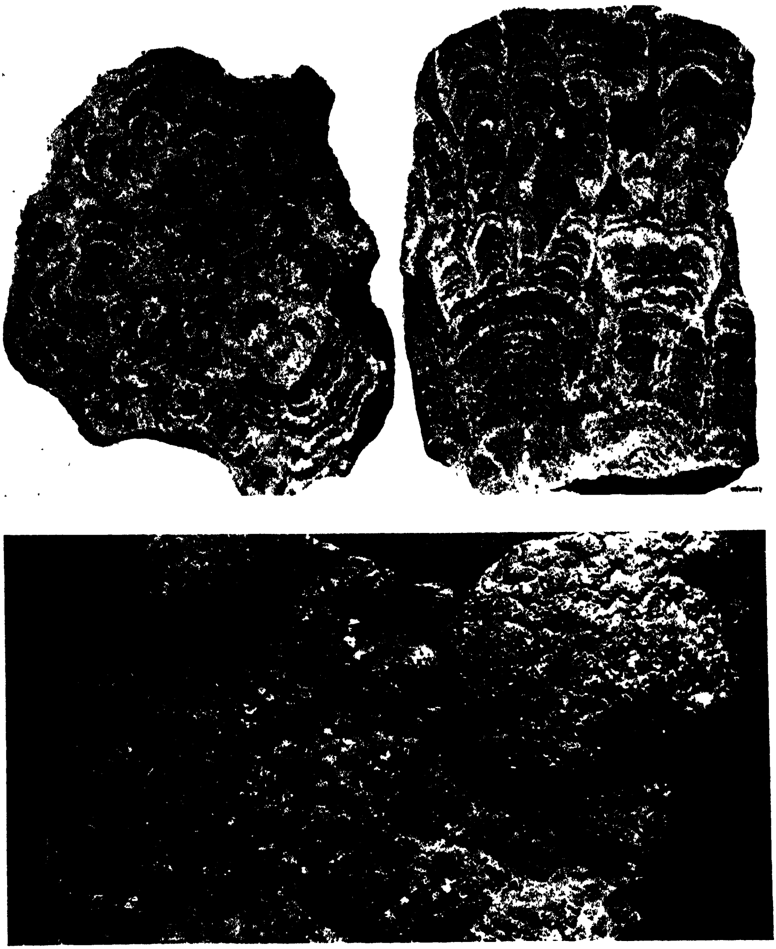


PLATE XXXI. Upper. Freshwater algal limestone of Oligocene age from reef-like deposits near Fairplay, Colorado, deposited perhaps by *Chlorellopsis* ($\times \frac{3}{4}$). Lower. Cauliflower-like or biscuit-shaped algal colonies from deposits of Pennsylvanian age at South Park, Colorado, deposited by algae similar to *Ottonosia* ($\times \frac{3}{8}$). (From Johnson, *University of Colorado Studies*; half-tones kindly supplied by the Editor.)

deposition of calcium carbonate from the water as the algae use the dissolved carbon dioxide in photosynthesis.

Deposits of marl in Michigan, also illustrating what may have occurred millions of years ago, have been attributed largely to activities of *Chara*. In its photosynthetic processes the *Chara* too absorbs carbon dioxide from water saturated

PLATE XXXII. *Halimeda opuntia*, abundant in 1 to 50 ft. of water at Key West, Florida. In the building of many so-called coral reefs the order of importance has been (1) *Lithothamnium*, a calcareous red alga, (2) *Halimeda*, a calcified green alga, (3) Foraminifera, microscopic animals, and (4) corals. (After Howe.)

with calcium salts, thereby precipitating calcium carbonate on the leaf-like blades of the plant. Massive beds of lake tufa seem to have been formed largely through similar activities of blue-green algae. Widely distributed and recently formed calcareous pebbles or "biscuits" show a radial and concentric structure that is associated with well-known blue-green algae, such as *Gloeocapsa* and *Gloeothece*. Certain marine algae, like

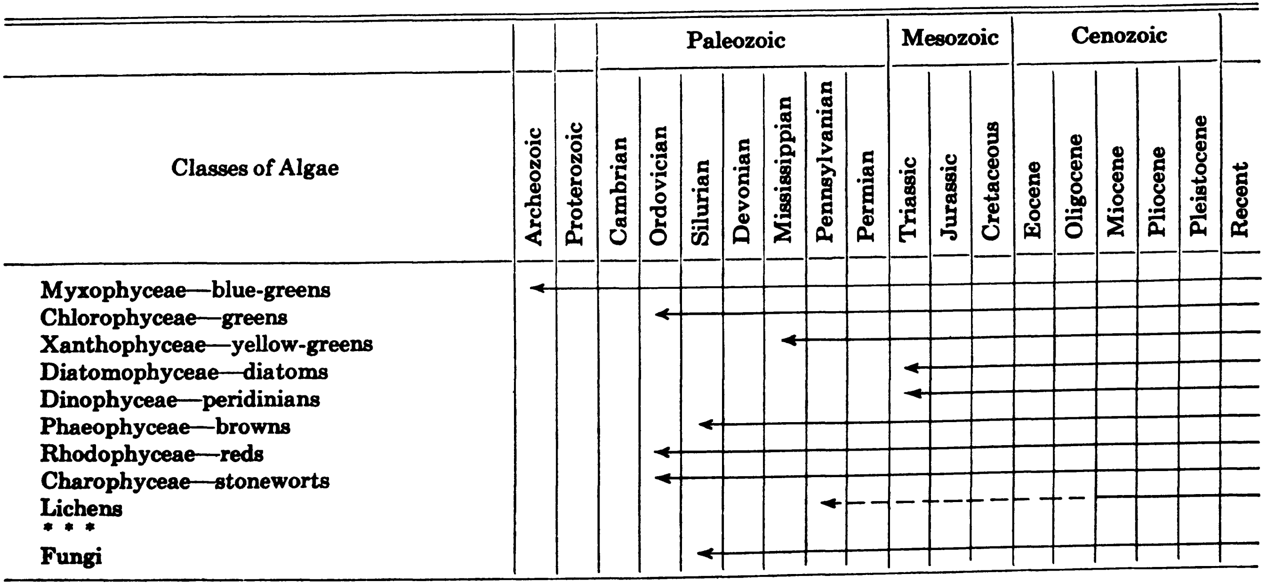
*Lithothamnium* and *Halimeda*, are important agencies through precipitation of lime in the formation of so-called coral reefs. As Howe has suggested, a new name—"algal reef" or "algal island"—should supplant "coral reef" in those formations obviously not or at least only secondarily associated with corals in their formation.

In certain parts of the Canadian Rockies biscuit-shaped masses of limestone several feet in height have been observed to be fairly abundant. These fossils may have been the result of growing communities of species of jelly-like red algae. Layers of calcite may have been laid down by the algae as they grew, the thickness of the deposits depending upon the rate of growth. The Fentons in discussing similar fossils near Banff think it possible that a layer of deposit and then a break in the fossil specimen may represent a year, corresponding to summer and winter in these ancient northern seas. There is of course no real evidence of "definite seasonal layers in limestones containing the fossils." The data in the region about Banff merely pointed to periods of several years of abundant plant life, separated by intervals of scarcity.

The precipitation of calcium carbonate by algae such as those discussed above has doubtless been going on ever since these plants began to grow in water. They have doubtless been of great importance in the formation of vast beds of limestone: either magnesium limestone or dolomite. C. D. Walcott in fact described several genera and species of "lime-secreting" algae from beds of Algonkian rocks, several thousand square miles in area and many hundreds of feet thick, occurring in Montana. These supposed algae all belong to the blue-greens, are thought to have lived in shallow and warm freshwater, and occur either singly or in great masses similar to our present-day algal reefs. Walcott has artificially classified such fossil algae as semispherical, flabelliform, or tubiform, based entirely on variation in form.

It must be admitted that we breathe more easily and feel considerably more secure when we leave the Archeozoic and Proterozoic and advance toward modernity several millions

TABLE 4. THE PRESENCE OF CERTAIN CLASSES OF ALGAE IN VARIOUS GEOLOGIC TIMES. FUNGI ARE ADDED TO COMPARE WITH LICHENS. *Adapted from Pia.*



of years, into the Paleozoic. We should keep in mind, however, that even in the Paleozoic the earth had far from "passed her time of youth." According to Pia (see Table 4) all fossil algae except the diatoms and peridinians go back at least to some period in the Paleozoic.

The algae present during the older Paleozoic—the Cam-

PLATE XXXIII. *Lithothamnium glaciale* from shallow water, Topsail, Newfoundland; widely distributed in the northern seas; begins growth on shells and pebbles, later becoming free. Covers bottom in deep layers for several miles in 10 to 20 fathoms of water off the coasts of Spitzbergen and Nova Zembla. (Courtesy M. A. Howe.)

brian, Ordovician, and Silurian periods—were probably salt water forms belonging to the greens, the blue-greens, the browns, the reds, and the stoneworts. If we use the term "calcareous algae" to apply to those forms in which the plant body is practically completely incrusted with lime, we may say that most fossils belong to them. Dr. Walcott described several impressions on pieces of Cambrian shale from British Columbia as distinct species of algae suggesting affinities

with plants living today. It is of interest by way of comparison to know that fossils of marine animals are very abundant in the rocks of the older Paleozoic.

We cannot here discuss the multiplicity of names that have been applied to algae occurring in the older Paleozoic. Reference to a few will give some idea of their appearance and re-

PLATE XXXIV. Miocene algal limestone quarry, Loretto, Leithegebirge, near Vienna, Austria. Extensively used in housebuilding in Vienna. Composed chiefly of fragments of *Lithothamnium*, especially abundant in lower strata shown above. (After Pia, courtesy of M. A. Howe.)

lationships. The large concentrically layered structures to which the name *Cryptozoon* has been applied are thought not to be wholly algal in origin. The mass of worm-like tubules having a diameter of about .04 millimeter—*Girvanella*— from the Ordovician limestone of Scotland bears resemblance to members of the family Codiaceae, although the sheath-like remains also suggest the blue-greens. Zalessky named minute yellow bodies of cell groups in a gelatinous matrix, from the Ordovician, *Gloeocapsamorpha*: similar to our present-day

blue-green *Gloeocapsa*. *Epiphyton* from the Cambrian and *Palaeporella* from the Ordovician were tubular or funnel-shaped. *Cyclorinus* bears a close resemblance to the living *Bornetella*. *Dimorphosiphon*, perhaps the oldest of the Codiaceae, is related to *Halimeda* which is today important in the formation of algal reefs. *Sphaerocodium* from the Silurian

PLATE XXXV. A *Lithothamnium* reef at Huingsisi, Malay Archipelago, at extremely low tide. (After Weber-van Bosse, courtesy of M. A. Howe.)

is most like *Codium;* and *Solenopora* seems to be related to *Lithothamnium*.

Seward's composite picture of what an Ordovician sea scene must have looked like will complete our summary of the early Paleozoic:* ". . . an expanse of water; clouds, blue sky, and sunshine as we see them today . . . curved lines or rings of calcareous rocks, consisting in part of coral-like masses of algae, thrown up by the waves to form the margins of lagoons, the light vivid green of the enclosed shallow wäter forming a striking contrast to the darker blue of the deeper water of the surrounding sea. . . at low tide we should prob-

* From Seward: *Plant Life through the Ages*. By permission of The Macmillan Company, publishers.

ably see Green, Brown, and Red seaweeds. . . we are conscious of a 'world dreaming of things to come.' "

If we move along a few million years we come to the Devonian: rocks of limestone with corals and other marine forms, of* "red sandstones and grits, conglomerates and shales, sediments in shallow water containing occasional fragments of terrestrial plants in company with strange armoured fishes and gigantic crustaceans." In the Devonian occur the first evidences of a very significant change in the earth's history: an ushering in of a land flora. This fascinating story we cannot digress to discuss.

In this period of great development of fishes and crustaceans we naturally inquire into the food supply of such creatures. The algae we discussed above are still represented today in their offspring. There must have been in addition enormous quantities of plankton, both plant and animal. The structures of the planktonic organisms were too delicate for fossilization, but our knowledge of the food of present-day young fishes and crustaceans makes it certain that marine plankton in great abundance was necessary for the food of the animals then present.

The later Paleozoic era consisting of the Mississippian, the Pennsylvanian, and the Permian may perhaps be dealt with as a unit as far as the algae are concerned. One new group of algae, the yellow-greens, seems represented for the first time. The lower Carboniferous (that is, the Mississippian and the Pennsylvanian) rocks contain numerous fossils of calcareous algae discussed previously. *Spongiostroma*, *Ortonella*, *Mitcheldeania*, and *Solenopora* all belong to the group of reef-building algae. In the Permian is found a fossil alga of the genus *Pila* composed of solid colonies that remind one of the yellow-green *Botryococcus*. Perhaps the most interesting phenomena of this period are the "boghead" coals occurring in many parts of the world, consisting of brown rocks, rich in oil and containing evidences of blue-green and green algae.

* From Seward: *Plant Life through the Ages*. By permission of The Macmillan Company, publishers.

The algae may have been "blooms" of plankton. At any rate it is not far-fetched to imagine freshwater and brackish pools in the swampy forests of equisetums, tree ferns, and club mosses containing "pond scums": ancient and honorable "amphibian spit."

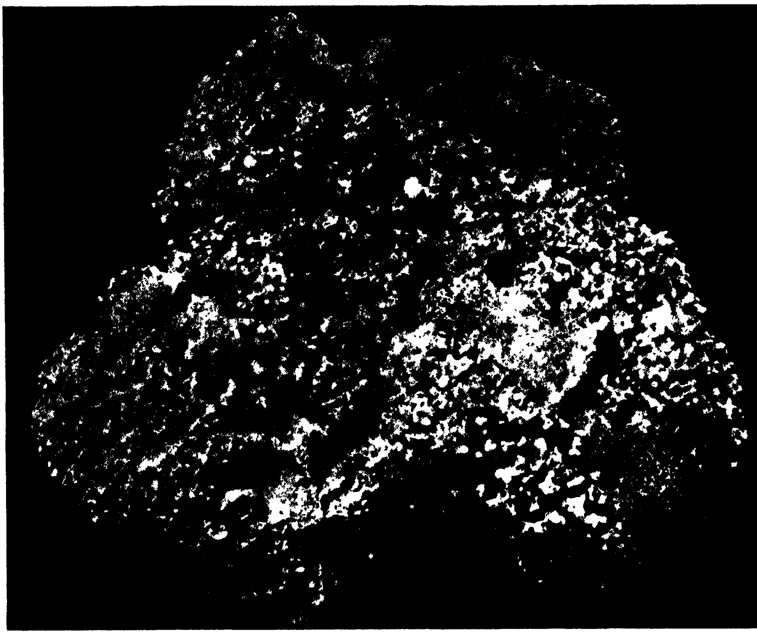


PLATE XXXVI. *Lithophyllum*, a calcareous red alga on surf-beaten rocks at low-water mark, mouth of Guanica Harbor, Puerto Rico. (Courtesy of M. A. Howe.)

The Mesozoic saw the development of enormous numbers of diatoms and of animal-like plants (or plant-like animals) known as peridinians or dinoflagellates. These latter are "armored" algae having in the main an elaborate covering of specially constructed and definitely arranged plates.

Although fossil diatoms have been reported from the Silurian and from the Devonian and from the Mississippian, Pia thinks that the oldest well-established siliceous fossil is *Pyxidicula* from the Jurassic, some 190,000,000 years old.

*Coscinodiscus* is a little younger along with *Actinoclava*, from the Cretaceous. It is in the Cretaceous and more especially in the Tertiary that the diatoms reached maximal production and abundance. This is evidenced by the enormous fossil beds composed of the silicon remains of diatoms, found practically the world over. Albert Mann believes that most of the diatoms from these fossil beds, both freshwater and marine, were bottom forms rather than surface plankton.

The great freshwater diatomaceous earths are known in the United States from Keene, New Hampshire; Montgomery and Cunningham, Alabama; Carson City, Nevada; Ludlow, New Jersey; and in Europe from Luneburg, Germany. Great deposits of marine fossil diatoms occur in the United States at Nottingham (Maryland) and at Monterey and Santa Monica (California); also in Oamaru, New Zealand; Kekko and St. Peters, Hungary; Ananiev, U.S.S.R.; Moron, Spain; and Sendai, Japan.

As mentioned briefly in a previous chapter the greatest and most unique bed of fossil diatoms in the world is located at Lompoc, California. It has an area of 12 square miles, has a depth of nearly 1400 feet, and is nearly pure diatom shells with scarcely a trace of sand, clay, gravel, or lime. Mann attributes this enormous deposit to "the concentrating effect of wind and tide on the plankton of the open sea, continued for long ages at one place." Diatomaceous earth was at first confused with "rottenstone," a polishing material mined in Tripoli, and even now may be bought at the drug stores under the name of "Tripoli powder." It has been estimated that as many as 40,000,000 individual diatoms may occur in a single cubic inch of some diatomaceous earths.

We now come to geologically recent times: from about 25,000 years ago to the present. During that time we have had no great glaciers, no great droughts, and no great changes in the boundaries between sea and land. Many kinds of algae occur throughout the entire world, perhaps just as they have occurred these thousands of years. Many present-day diatoms, for example, are practically identical with those found in

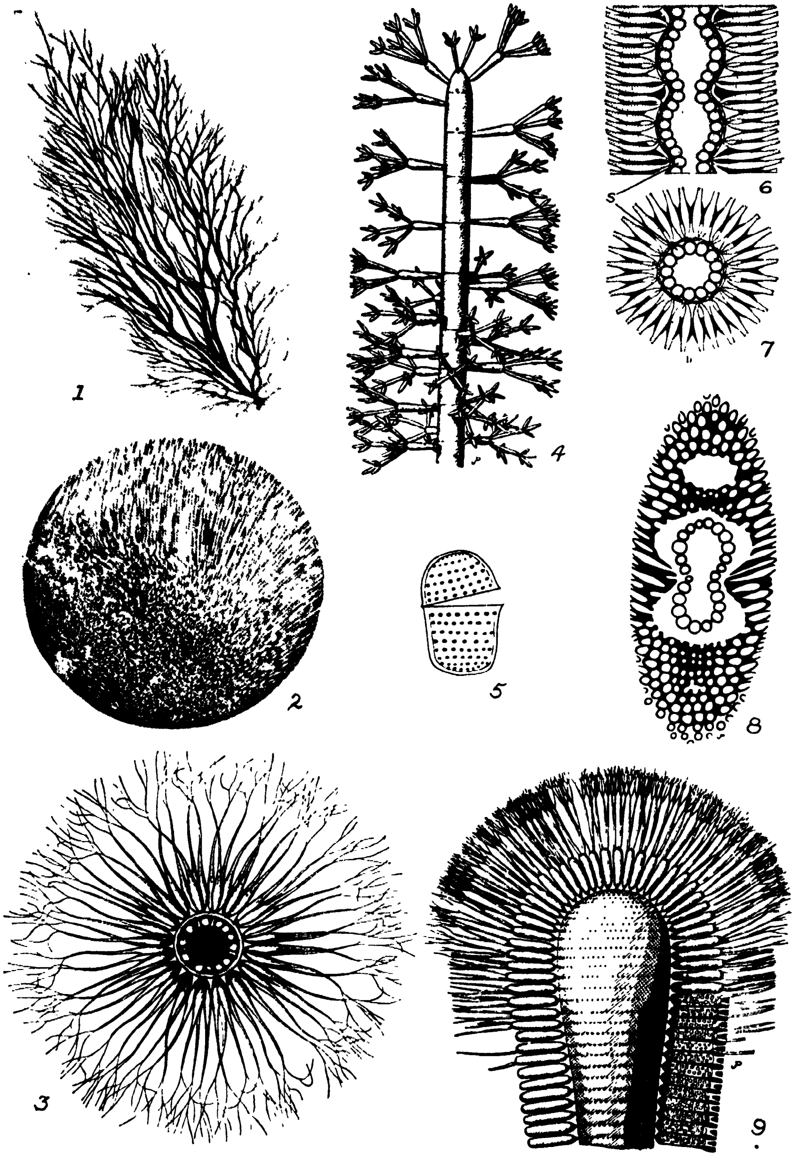


Plate XXXVII. Algae of the past: 1, *Thamnocladus* (Devonian); 2, *Solenopora*, thin section of rock (Ordovician); 3, 6, 7, 8, *Diplopora* (Triassic): (3, a whorl partly restored; 6, longitudinal section; 7, cross section; 8, thin rock section); 4, *Primicorallina* (Ordovician); 5, *Pyxidicula* ( = *Stephanopyxis*) (upper Lias); 9, *Triploporella* (upper Jurassic); (s, spores or cysts). (After Pia in Hirmer: *Handbuch der Paläobotanik*, courtesy, R. Oldenbourg.)

fossil beds described above. Other species once abundant are not now to be found. No great division of the algal flora is known positively to have flourished at one era and to have disappeared at a later one, as have some seed ferns, primitive conifers, fishes, and mammals. Aquatic habitats have remained fairly constant for millions of years and our present algal flora has quite likely been represented all this time.

We have in this chapter attempted to "begin at the beginning" and we have seen the available evidence for algal antiquity. Due to the difficulties of fossilization of algal forms some of the evidence is fragmentary; other data appear, however, to be incontestable. Most scientists agree that life began in the water, and there is abundant proof for the existence of diverse aquatic animal forms millions of years ago. It is unthinkable that these ancestral animals could have long survived without the photosynthetic activity of aquatic algae in making solar radiation available to them in usable and edible organic compounds similar to carbohydrates, fats, and proteins. We are justified then in concluding that algae have been a part of the earth's aquatic flora since earliest geologic time.

## Chapter XI

# ALGAE AND HUMAN WELFARE

Since the opening sentences of this book we have had quite a lot to say about the algae. We now know something of their processes, their habits, their manner of growth, their dwelling places, their ancestry, their abundance. If you are a practical, matter-of-fact reader, you are asking yourself, perhaps subconsciously, what can be the use of these algae? How have they ever directly concerned me? What is their value, if any, to mankind?

Such questions are perfectly legitimate and proper, they have been asked many times before, and we shall try to answer them.

Of course you may have at this very instant a blue-green alga attached to the walls of your duodenum or your jejunum. If so, do not in the least be alarmed. You very probably could not detect such an endozoic guest if present. And the number of your days upon the earth will doubtless be neither increased nor diminished by such an internal visitor.

It is true, however, that algae may become noxious and harmful to man as well as to a few other animals. There have been occasional reports in the press of the deaths of horses and cattle after drinking water containing quantities of green algae. Such statements have practically never been actually substantiated as matters of cause and effect. Quite to the contrary, squirrels and cattle and many aquatic animals have been observed devouring algae with apparent gusto, and no casualties resulted. This particular indictment of the algae generally may be summarily dismissed because of a lack of factual support.

It is interesting in this connection, however, to cite some rather careful analyses of water containing species of blue-green algae, made at the University of Minnesota. Quantities

of microscopic algae forming water blooms are objectionable normally not only because they render the water unfit for drinking purposes (see below), but also because their presence may discourage bathers and become obnoxious to near-by residents. Miss Tilden reports poisoning and death of livestock in Minnesota, due apparently to drinking water containing excessive blooms of blue-greens. Water with an especial bloom of *Microcystis*, causing death to sheep drinking the water, was analyzed at the University and found to be highly toxic. When given to guinea pigs and rabbits in very small amounts, death occurred in from twelve to fifteen minutes. The nature of the poison is not known.

The swimmer need not be unduly alarmed. If the water is not foul and does not have a "soupy" appearance, it is very doubtful that discomfort other than psychological will be felt by the bather even during bloom time. Enormous waves of *Anabaena* and *Microcystis* (both blue-green) occur every year in the shallower parts of Lake Erie during July and August, but wind action nearly always prevents any undue mass accumulation. As a consequence bathers practically ignore the "nuisance."

In Chapter IX we discussed at some length the deleterious effects upon certain seed plants of epiphytic and endophytic algae. In some cases the injury appears to be secondary rather than direct: shading of the leaf by the formation of dense mats which inhibit maximum photosynthesis. A few genera of algae, like *Cephaleuros*, cause serious injury by initiating structural modifications that result in discolored cushion-like patches on the leaves of such plants as tea, members of the citrous group, and magnolia. In many tropical and subtropical regions the latter kind of injury may reach considerable economic proportions.

Algae have for many years been known to be important causal agents in the contamination of water supplies. Foul odors and bad tastes occurring in city water reservoirs may be brought about by a superabundance of algal forms or by other organic matter. Most algae make oily substances in the course

of their many syntheses, and such compounds may be the source of the noxiousness. Certain odors are attributable to specific algae, such as the "pig-pen odor," the "fish odor," or the "marsh odor" of some blue-greens. The fishy odor of the golden-brown *Uroglenopsis* in reservoirs is often a concern of sanitary engineers. The intensity of the odors of course increases with an increase in the number of organisms present.

It has often been taken for granted that the algae elaborate special chemical compounds that are responsible for such unpleasant and sometimes offensive odors and tastes. As a matter of fact, other than the Minnesota findings mentioned above, almost no data are available to support the assumption. Processes of oxidation and decay among the algae are essentially the same as for other green plants.

In addition to the accumulation of oil in the cells, two other sources of contamination of water supplies are evident. In the first place the peripheral slimy covering common to most algae makes ideal lodgment for all sorts of bacteria. In the second place many algae grow and reproduce with such prodigious rapidity that mass accumulation soon results. This is especially true in waters of small ponds and protected harbors of lakes. The same phenomenon may become evident even in streams in times of drought when the current is sluggish and the water is ponded. Such a mass readily undergoes decomposition with both complete and incomplete oxidations. The gaseous output from these oxidations together with the solid substances resulting thereform probably accounts for most of the contamination. These are often quite enough, of course, to make the water unfit for drinking.

When one realizes that an alga rarely and perhaps never grows unassociated with other plants, such as various kinds of algae, many bacteria, and a few fungi, as well as flowering plants and even animals, it is unwise to assign these harmful and noxious manifestations to the algae alone. Even Dr. Heiser, the eminent physician who did so much for the health of the Filipino, seems temporarily to have forgotten his bacteria and other microorganisms in his haste to condemn

the algae. In his *An American Doctor's Odyssey* he refers to the filling of a slough near Manila "with good ground, converting the poisonous algal green to the fresh green of grassy park." And the usually alert Henry Williamson has Solar the Salmon avoiding sluggish and warm water where the algae growing on the roots by the shore "gave off the gases of death." Dead and dying algae may be associated with contamination, but so might other plants, as well as animals, in similar states of decadence.

Algae sometimes become so matted on the surface of water as effectively to prevent aeration for fishes living in shallow ponds and pools, In fish ponds the oxygen depletion during the night by respiration of both the algae and the fishes often produces an acute situation. Just before daybreak hundreds of young fishes in fish hatchery ponds full of algae may die of suffocation. Mechanical injury and sometimes death may take place when young fish become imprisoned in the tangled mass of filaments of larger forms of algae. Conversely of course these same tangles of algae often provide a haven from too much sun and from larger fishes.

The contamination of city reservoirs and fish ponds by algae has been of vital concern ever since urban communities demanded pure water and since the agencies of over-fishing and pollution so depleted our streams and lakes as to make requisite the artificial rearing and planting of fish. It early became necessary to ascertain ways and means of eradicating algal growths from water. Just after the turn of the present century Moore and Kellerman recommended the application of dilute solutions of copper sulfate, or blue vitriol. Copper seems to be particularly poisonous to many algae. Concentrations as low as 1 part of $CuSO_4$ to 20,000,000 parts of water are destructuve to *Uroglena;* four times that concentration is fatal to *Scenedesmus* and *Kirchneriella;* and the ratio 1:500,000 is sufficient to eradicate most forms.

Water containing such quantities of copper sulfate is not unfit for human consumption. It is therefore a relatively simple matter to rid a pond or reservoir of noxious algae by the

application of $CuSO_4$. The practical method usually recommended is to row a boat, to which has been tied a sack of blue vitriol, several times through the pond, allowing for the gradual solution of the chemical. In small artificial pools, such as swimming pools, it is well to drain out the water and clean both bottom and walls with some good abrasive or neutral solvent cleanser. Then after thorough rinsing one of the "copper solutions" on the market may be applied, according to directions.

If the reservoir contains fish, precautions are necessary because $CuSO_4$ is detrimental to many aquatic animals, in varying degrees. Sodium arsenite* is destructive to some algal growths and causes minimum harm to fishes. It results, however, in brownish water of low transparency and in some way militates against good "crops" of fishes in hatchery ponds. The excess growth of algae, if of the filamentous type, may be manually removed with pitchforks and rakes, and in many fish ponds this procedure appears to be preferable.

A more recent and workable suggestion preventing contamination of water reservoirs and fish ponds appears to lie in proper drainage. The excess water allowed to flow from the reservoir or pond is usually surface or near-surface water. This makes no provision for elimination of bottom water which usually is low in oxygen and surfeited with products of organic decomposition. When the level of the impounded water is low and the incoming flow from the stream is greatly reduced, the water suddenly becomes clear and transparent. Clear, non-flowing water over a bottom rich in organic matter rapidly leads to a "bloom" of plankton algae. Such an accumulation quickly decomposes and contamination results. An outlet which allows for flushing out of the bottom and continued circulation of the water prevents excessive algal growth, particularly of phytoplankton.

Langlois has met with considerable success in cutting down

* Commercial "weed killers" probably contain arsenic in solution in the form of $NaAsO_2$, with lesser amounts of $Na_3AsO_3$ and $Na_2HAsO_3$. See Surber (1932).

the production of algae by stocking Ohio fish ponds with young crayfish. They keep the water nearly constantly turbid, an inadequate penetration of light results, and growth of plankton algae is rather effectively stopped. Wiebe reports similar practices for some of the southern states.

Other malodorous conditions arise at almost any time a quantity of algae collects in masses. Along seashore, particularly after storms, seaweeds and other marine algae may collect in piles and heaps. Such is the case, for instance, with sea lettuce (species of *Ulva*).

TABLE 5. CHEMICAL ANALYSES OF SOME WISCONSIN ALGAE. (Figures indicate percentages of dry weight.) *After Birge and Juday*

| Alga | Nitrogen | Crude Protein N ×6.25 | Ether Extract | Pentosans | Crude Fiber |
|---|---|---|---|---|---|
| Microcystis | 9.27 | 57.94 | 2.67 | 4.97 | 0.26 |
| Anabaena | 8.27 | 51.69 | 1.11 | 4.81 | 0.63 |
| Volvox | 7.61 | 47.56 | 5.54 | 1.00 | 6.32 |
| Cladophora | 2.77 | 17.31 | 2.54 | 8.32 | 18.47 |
| Spirogyra | 3.47 | 21.68 | 2.75 | 10.70 | 0.64 |
| Diatoms | 3.66 | 22.87 | 13.60 | 2.87 | 1.43 |

| Alga | Nitrogen Free Extract | Ash | $SiO_2$ | $Fe_2O_3$ and $Al_2O_3$ | $P_2O_5$ | CaO | MgO |
|---|---|---|---|---|---|---|---|
| Microcystis | 34.82 | 4.31 | 0.13 | 0.84 | 1.18 | 0.92 | 0.63 |
| Anabaena | 39.40 | 7.17 | 0.95 | 1.27 | 1.21 | 1.42 | 0.70 |
| Volvox | 34.30 | 6.28 | 0.24 | 0.80 | 2.50 | 1.10 | 0.93 |
| Cladophora | 35.14 | 26.54 | 7.10 | 1.80 | 0.32 | 3.26 | 1.62 |
| Spirogyra | 65.88 | 9.05 | 0.24 | — | — | — | — |
| Diatoms | 22.60 | 39.50 | 30.78 | — | — | — | — |

So much for the harmful or noxious aspects of algae: suppose we now look at the other side of the picture and inquire into the beneficial phases of the subject.

It must be recalled at the outset that algae are for all intents and purposes green plants. Given an adequacy of solar energy, raw materials, and proper temperature, algae make

complex chemical substances referred to as foods: carbohydrates, fats, and proteins. Some results of chemical analyses of a few Wisconsin algae are given in Table 5 on the preceding page.

Much has been written of the dependence of the world upon the products of agriculture. These products—plants and animals—have long been known to be our only sources of food, directly or indirectly. We have innumerable statistics on such matters as the yield of corn per acre in Illinois, the value of a bale of cotton in Georgia, the terrific loss in farm value by soil erosion in the United States, and the number of board feet of lumber in a giant Sequoia of the west.

Until relatively recently it has rarely occurred to any of us to ascertain the worth of a swamp, the value of a pond, the good of rivers, or the precise import of the sea. In fact, America has gone practically insane in her attempt to drain swamps, to fill up ponds, and to make rivers more capable of ridding the land of water, as well as good soil, in a minimum of time. The Dutch have gone us one better and made farm land out of the sea.

The primary foods of the animals that inhabit the water are aquatic plants, largely algae. The value of a pond or lake or stream might be measured in many ways, but an estimate of the algal productivity of one will give us an approximation. If the 200,000 acres of inland waters of the State of Ohio were "potential soil" for algae and hence for fishes, we should be able annually to "harvest" some 28,000,000 pounds of fish having a possible energy value of perhaps 14 billion Calories. A very conservative estimate of the crop of algae for a single year from these 200,000 acres is a billion pounds. Nobody knows exactly the energy value of an acre of algae, but suppose it were equal to that of an acre of corn. The annual energy value then of Ohio algae reaches the enormous figure of over 300 billions of Calories. These figures are the merest approximations, little more than guesses in fact, but they point to a significant fact. Ohio fishes which feed upon algae (directly or indirectly) are worth 14 billion Calories;

Ohio algae, if possible to harvest and utilize directly, would yield something like 300 billion Calories. The ratio is over 20:1 in favor of the algae.

What happens to the potential value of algae when fed upon by fishes? Why is the net return in Calories from the fishes so much lower than the value of the algae themselves? Are such harvests possible of realization, even on a small scale?

We have noticed previously that different algae occur in bodies of water at different times. There may be an almost

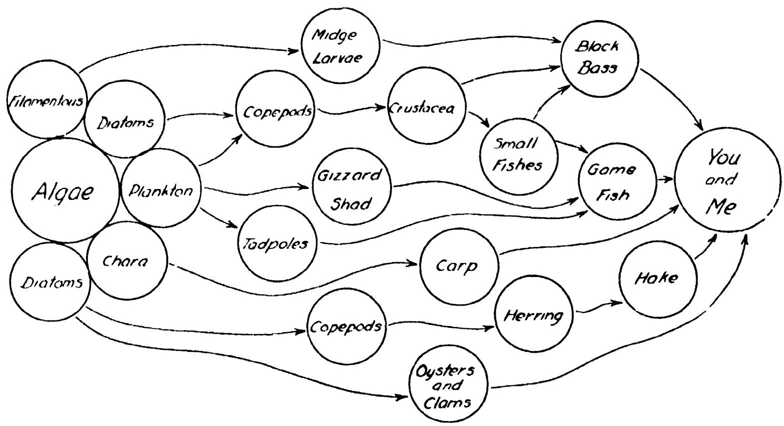



FIG. 11. Some food chains.

continuous growth during certain seasons due to the rapid succession of one community of algae by another.

An Iowa aquiculturist once became interested in raising fish on a pond located on his farm. In one year he harvested a "catch" of an average of 333 pounds of fish to the acre. These fishes of course used in some form great quantities of algae. From studies of lakes in Wisconsin, Birge and Juday estimate the annual production of total plankton to be over 10,000 pounds of dry weight per acre, assuming fifty turnovers each year. In Lake Mendota alone they find that the dry weight of total plankton varies from a minimum of 126 pounds to the acre in February to a maximum of 256 pounds in December. The living material would weigh ten to twelve times that much.

Let us examine some of the many well-known food cycles involving algae, aquatic animals of various kinds and finally you and me (Fig. 11). A quite circuituous route is represented from algae through copepods, small and large crustaceans, small fishes, big fishes, and eventually man. It is obvious that the larger the chain, the greater the amount of food necessary for growth and locomotion of the intermediaries, and consequently less of the original energy value possible for mankind.

Another chain of events with fewer links is that involving the gizzard shad. Such a fish consumes quantities of plankton algae and is in turn eaten by game fishes. Albert Mann in working with marine organisms reached the succinct conclusion: no diatoms, no hake, because hake feed on herring, herring on copepods, and copepods on diatoms. Emmeline Moore indicates another cycle in which the baseball classic "Tinkers to Evers to Chance" becomes biologically "filamentous algae to chironomid larvae to black bass."

The number of aquatic animals living partly or wholly on algae is almost legion. Mention has just been made of the gizzard shad, the hake, chironomid larvae, and copepods. A short list of others includes mayfly larvae, midge fly larvae, shrimp and other crustaceans, the Hawaiian reef fish as well as the young of many fishes both marine and freshwater, oysters and mussels and other bivalves, worms, water-fleas, and tadpoles. As a matter of fact the gizzard shad and the tadpole are of the greatest aid to the collector of algae with few utensils. An examination of their stomachic contents will reveal a concentrated sample of the plankton in the body of water from which these living townets are taken.

Some of these animals utilize the plankton forms while others obtain the attached and bottom algae. The oyster appears to be directly dependent upon the available supply of diatoms. The California sea mussel is an example of a sort of a sedentary townet in which ciliary currents carry in water containing dinoflagellates and diatoms. After a seven months'

investigation near La Jolla specialists of the Scripps Institution of Oceanography report that the stomachic content of this mussel showed 97.4% dinoflagellates to 2.60% diatoms, although the sea water gave almost opposite figures. This of course brings up the matter of selective feeding on the part of lower animals, about which there is considerably more speculation than fact. We can perhaps rule out immediately any tendency toward a deliberate choice of food and rely on the mechanics of ingestion for the source of our answer. The mussel in this case seems to use few pelagic diatoms in comparison to the sedentary forms.

It is only fair to say, in trying to analyze food cycles of the sea, that certain marine bacteria may be able to change carbon dioxide to organic carbon without sunlight. In this way an important primary food supply for mud-eating animals in particular is supplied, apparently removing the necessity for dependence upon photosynthesis. The nitrifying bacteria, for example, are autotrophic, depending only upon such simple chemical compounds as ammonia, nitrous acid, and carbon dioxide. It is known that these bacteria exist in the sea, but their importance as sources of energy for animals is at present little more than a guess.

Perhaps you are mentally paraphrasing one of the Black Crows' terse finalities and thinking "Who wants to eat algae?" The angle of inclination of the average civilized nose changes perceptibly at the very mention of algae, often termed "frog slime" or "pond scum," in connection with food. And we readily admit that the use of algae as a direct source of food for much of the civilized world seems rather remote. We wish merely to record the fact—and it is a fact—that all of the algae of all the waters of all the lands are potential sources of colossal and almost unbelievable quantities of food and energy. Such a supply comes to us now in small part in the fishes and clams and lobsters that we eat.

How many people eat algae? What is the actual food value of algae when eaten directly by a Japanese peasant, an

Hawaiian fisherman, or a Brazilian tribesman? Suppose we briefly tour the world and see how many of its inhabitants are actually making algae an article of diet.

Few of us in America will acknowledge that algae furnish a source for anything that we eat, but let us inquire further. The sea furnishes practically our entire output. Perhaps the most important seaweed in the United States is Irish moss or carrageen (*Chondrus crispus*) which grows on our Atlantic Coast from Maine to the Carolinas. It is used in making blancmange and other puddings, as well as in jellies. Irish moss is about four-fifths water and one-tenth gelatinous matter, with smaller percentages of nitrogen, fats, calcium, sodium, bromine, potassium, magnesium, chlorine, iodine, and sulphur. The center of the Irish moss industry in America continues to be at Scituate, Massachusetts.

In New England towns along the coast another marine alga, dulse or sea kale (*Rhodymenia*), is eaten as a vegetable. An imitation of candied citron has been prepared by Colvin and Frye from the Pacific kelp, *Nereocystis*. It is called seatron. The agar of commerce, having its chief source in the orient, is now made in California. The agar industry will be discussed in another connection later in the chapter.

European consumption of algae as food is somewhat more than that in America. Irish moss for pudding; dulses, originally chewed when dried and before the days of tobacco, as condiments; laver or slake or slack (*Porphyra*) boiled and variously seasoned; green laver (*Ulva*) eaten after a preparation similar to that used for slack; and several other genera of marine forms utilized similarly constitute the bulk of the European trade.

In South American countries quantities of the blue-green *Nostoc*, as well as seaweeds, are boiled with garden vegetables to add flavor. In India *Spirogyra* and *Oedogonium* may be seen on the markets in dried packets, for sale.

It is, however, when we come to the orient that raising, harvesting, and using algae become a commercial industry. Edible algae under the general name of "limu" are used ex-

tensively in Hawaii as food, especially by the poorer natives. In fact seaweeds make up the major portion of their vegetable diet. The algae are eaten raw, and apparently the limu connoisseurs are able to distinguish varying degrees of palatability among the different species. Some limu will keep in edible condition for a long time, while other forms must be eaten the same day they are gathered. Limu may also be boiled with fish or shrimp or may be used to wrap up a pig or dog cooked underground. According to Setchell one *Limu kala* is used ceremonially. Setchell has listed some 109 Hawaiian names applied to limu. These appellations range alphabetically from *Aalaula* and *Alaalaula* through *Huluhuluwaeua* and *Kiki* to *Palapahakou* and *Wawahiwaa*. Some of the algal genera included are *Codium*, *Ahnfeldtia*, *Sargassum*, *Haliseria*, and *Ulva*.

The greatest use and consumption of edible algae occur in Japan and China. Tressler points out that much of Japan is mountainous and that her dense population makes it necessary to seek sources of food elsewhere than in agriculture. Her coast line amounts nearly to 180,000 miles and the quantity of marine algae along her shores is enormous. Although there are from 25 to 30 species of algae eaten by the Japanese, "amori" (*Porphyra*) and "funori" (*Gloiopeltis*) are the important ones under cultivation. Bundles of bamboo or other materials are sunk into muddy bottoms of water and these furnish lodgment for the spores of the algae. The spores germinate, the plants grow rapidly, and within three or four months the harvest is made.

Amori, kombu (species of kelp), and tengusa (*Gelidium*) are considered the most important of the Japanese edible seaweeds. Tressler estimates that nearly a thousand acres are given over to the cultivation of amori, yielding a crop worth from $150 to $300 an acre. Amori may be eaten raw or preserved for future use by drying in the sun. It may be baked until crisp and then eaten with soup or broth or made into a kind of sandwich known as "suchi." Kombu is one of the standard foods of Japan and comes from various species of

*Laminaria*, *Arthrothamnium*, and *Alaria* on the shores of the northernmost islands of the archipelago. Kombu may be cooked with meats and soups, may serve as a vegetable, may be put on sauces and rice, and may be used as tea.

It was mentioned earlier that agar was made on our own western coast (Tropico, California), but that principally the industry was oriental. It has been known for many years in Japan, China, Malaysia, and Ceylon as a commerical name applied to a dried gelatinous extract from certain species of red algae. Agar is made from the algae by a series of processes consisting of bleaching, cleaning, freezing at temperatures about $-10°$ C, and then removing the water by melting. It is about 75% gelose, 15% water, 4% ash, and smaller percentages of protein, fats, fiber, and silica.

Agar-agar is a favorite seaweed in China and Japan for jelly and as a thickener of soups and sauces. Its chief commercial value lies in its ability to form a firm gel upon cooling, and so is used in the making of ice cream, desserts, and various pastries. It is superior to gelatin in giving rigidity to soft canned fish in transport. It may also be used in clarifying liquors, as sizing material, and (in America and Europe) in the preparation of bacteriological media. As a laxative it has the properties of absorbing much water, of becoming a lubricant, and of serving as a mild stimulant.

From this short recital it is evident that algae in many countries are important items in one way or another in the diet of many peoples. It is only fair, however, to inquire a little into the actual food value of algae since various writers have made considerable claims as to the nutrient properties of such plants. About 65% of the dry weight of most edible algae is composed of complex carbohydrates with rather low digestibility. In fact Oshima places the digestibility of edible seaweeds of Japan at 67.7%, which is lower than that of any carbohydrate of common foodstuffs. The polysaccharide carbohydrates of agar, Irish moss, amanori, and kombu are not readily assimilable in the alimentary tract of man and other higher animals. Such hemicellulose groups as galactan, pento-

san, levulan, and mannan found in edible algae are almost unaffected by ordinary digestive enzymes.

Not much definite information is at hand regarding the digestibility of nitrogenous compounds of algae. Hoagland found that in certain algae of the Pacific Coast the nitrogen existed in a non-protein form. More data are needed before we can know the precise value of these nitrogenous materials.

For man then—not fishes, tadpoles, copepods, and crustaceans—algae cannot rate high as an energy supplying and easily assimilable food. They are relatively high in certain vitamins—some seaweeds are rich in vitamins A and E—and in valuable inorganic salts necessary for the human body, their iodine content is important in glandular treatment, their bulk and water-absorbing qualities make them excellent laxatives.

Stanford over a half century ago observed a colloidal substance formed when certain laminarias (kelps) were soaked in fresh water, and gave it the name algin or alginic acid, having the chemical formula $C_{21}H_{27}O_{20}$ (Hoagland & Lieb). Alginic acid is insoluble in cold water, absorbs many times its weight in water, and becomes hard and horny and resistant to solvents when dry. Many metallic alginates may be formed, but the most useful is sodium alginate. The chief uses of the alginates are as sizing materials in waterproof varnishes, as dyes, and as rubber-algin substances such as knife-handles, buttons, and combs. Sodium alginate has found widespread use as a stabilizer in dairy products. It also stimulates growth in white rats.

Seaweeds were burned on the European coast for many years to secure "pot-ashes" needed to supply the alkali for the manufacture of soap and alum. The manufacture of soda from common salt decreased the value of the seaweed ash industry, and even the discovery of iodine in 1812 failed to resuscitate it. About sixty years later iodine was recovered from the mother liquors obtained in the making of sodium nitrate from caliche. At present Chile saltpeter supplies the bulk of the iodine of commerce. According to Burd some species of brown

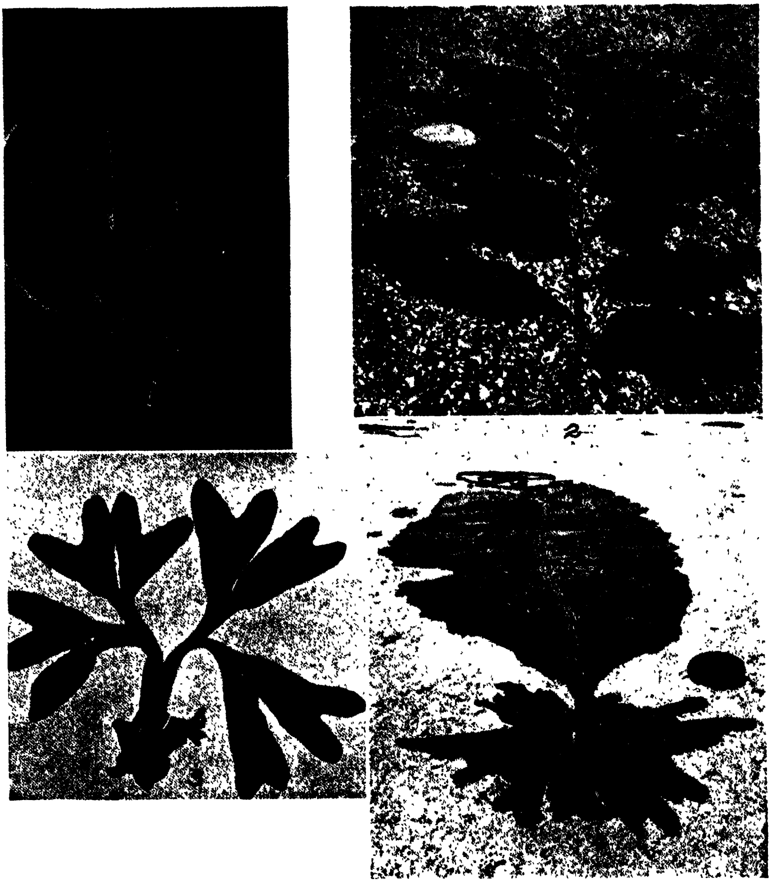


PLATE XXXVIII. Larger marine algae: 1, Young plant of *Nereocystis*; 2, *Macrocystis*; 3, *Fucus*; 4, *Alaria*. (Report No. 100, Bureau of Soils, U. S. D. A.)

algae contain in the blades as much as 0.29% iodine in *Macrocystis*, 0.38% in *Pelagophycus*, 0.14% in *Nereocystis*, and in whole plants of *Laminaria* 0.49% (dry weight computations). Tressler reports that the 400,000 tons of green seaweeds collected in Europe annually yield about 175 tons of iodine, 10,000 tons of potassium salts, 3000 tons of crude salt, and 7000 tons of crude washing soda. The iodine content of

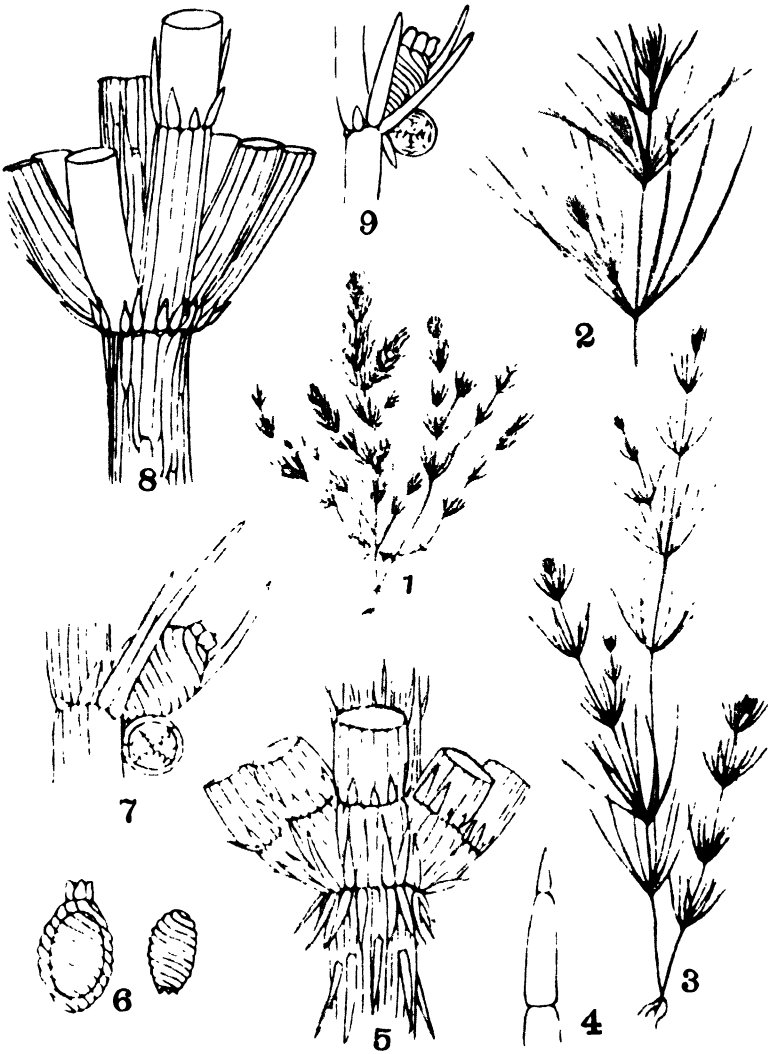



PLATE XXXIX. *Chara*, the stonewort: 1–3, vegetative plants; 4, apex of branchlet; 5, 8, portion of stem with base of whorl; 6, oogonium and (right) oospore; 7, 9, fertile "node." (After Groves and Stephens.)

eggs and milk may be increased by feeding hens and cows certain kinds of marine algae.

Before the World War much of our supply of potash came from Germany. When this was cut off, we began to investigate sources of our own. Attention was early turned to the kelps of the Pacific Coast. It was found that species of *Macrocystis*, *Nereocystis*, and *Pelagophycus* contained a considerable amount of potash in the form of potassium chloride, percentages as high as 30% dry weight being reported. Potash can be secured from deposits in our own west and southwest, and this is more economically obtained than from kelps. It should not be forgotten, however, that the brown algae represent vast sources available for potassium salts when the need arises.

Farmers near the seashore have probably used the large marine algae as direct fertilizer for many years. Soldiers unfamiliar with such a practice were much impressed during the late war with the thriftiness of the French peasants in bringing in quantities of seaweed, scattering it over their farms, and allowing it to decay or plowing it under. Similar practices have been known from the eastern coast of Asia, from Japan, from parts of South America, from New England, and from Eastern Canada. Potato gardens of Alaska are frequently fertilized with kelp.

According to the press a new German process has been perfected by means of which seaweed may be mixed with cement to make light-weight building blocks having good heating qualities. Sawdust, fine wood shavings, or peat may be used in place of the algae.

It has long been known that many kinds of plants and plant parts may be made into paper: in fact paper of a kind can perhaps be made from almost any plant. It is probably not so generally known that natural paper has been made from algal mats for perhaps millions of years. A thin covering of algae with filaments closely intertwined and appressed may upon the evaporation of the water and subsequent rapid drying in the sun produce a paper that has considerable resemblance to

Japanese lens paper; often however the paper is very coarse and matted. A sample of such "lens paper" recently collected in Louisiana was made up of nearly pure strands of *Tribonema* with occasional filaments of *Oedogonium* and *Spirogyra.*

To those who are accustomed to think of landscapes in terms of forests, ornamental plantings, grasslands, or waving fields of grain, the place occupied by algae in the scheme of improvement will seem relatively small. The various colors seen on exposed cliffs, rocks, and stones are often due to the growth of some lichen, whose chlorophyllous constituent is an alga. In extremely arid regions where a mere smattering of rain occurs once or twice a year, relief from the monotony of sameness is afforded by the sudden appearance of "green soil" upon the advent of moisture. The greenness is due to the rapid growth of soil algae, such as *Botrydium.* The importance of the subaerial algae of the tropics is discussed in a previous chapter.

In an earlier chapter reference was made to the enormous deposits of diatomaceous earths in various parts of the world. Throughout the years diatomaceous earth has been variously used. It is at present extensively employed as an insulating material for coating steam pipes or pipes of refrigerating plants and for lining walls of blast furnaces. Many tons are annually consumed in the filtration of oils and sirups. As a polishing substance it has been largely replaced by such materials as carborundum, but it is still quite popular for polishing silverware. In making dynamite diatomaceous earth formerly served as an absorbent for liquid nitroglycerine. Substances like wood-meal have in recent years practically replaced it. Perhaps the oil deposits of the world, particularly those of California, have had their origin in oil originally made in living diatoms.

The use of diatomaceous earth goes back many years. Mann records that the Emperor Justinian in 532 A.D. gave directions that in the repair of the Church of Saint Sophia in Constantinople bricks be made of diatomaceous earth, because of their lightness.

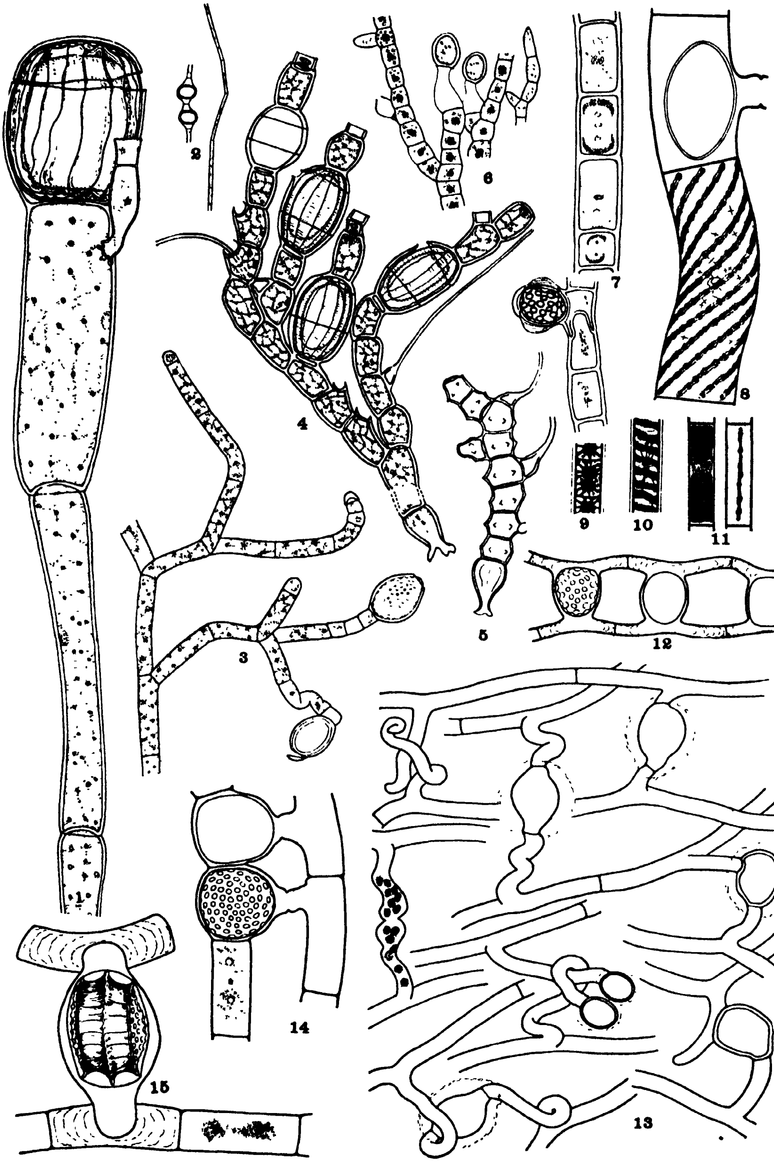



**Plate XL.** When one collects filamentous algae he is likely to locate some of these genera: 1, 2, *Oedogonium*, a large and a small species drawn to scale; 3, *Oedocladium*, found usually in damp soil; 4, 5, *Bulbochaete*; 6, *Trentepohlia*, a subaerial alga; 7, *Pleurodiscus*; 8, *Spirogyra*; 9, *Zygnema*; 10, *Spirogyra*; 11, *Mougeotia*, two views of plate-like chloroplast; 12, *Zygnemopsis*; 13, *Mougeotia* with curious manner of conjugation; 14, *Zygnema*; 15, *Debarya*. (1, after Jao; 8, 12, 14, 15, after Transeau.)

It seems fitting, in bringing to a close a rather brief survey of our knowledge of the relation of algae to human welfare, to mention the place of algae in programs of fundamental research in biology. Algae are usually present in most bodies of water and available to any investigator. Many species may be successfully grown in culture, their anatomical and structural features are relatively simple (a single cell is often an organism), large numbers of individuals may be present simultaneously, and several generations may be grown in a short time. In studies involving microchemical analyses of cell walls and protoplasts, in investigations of hydrogen ion concentration *in situ*, in ascertaining the role of mineral elements in plant metabolism, and in cytological and genetical investigations, many algae are very much worth while as "subjects" for research. Algae have been utilized considerably in the past and might well receive additional consideration in the future.

Algae then are of interest to us in many ways. They are sources of food and energy to the aquatic animal population and indirectly to you and me because of their ability to carry on photosynthesis. They live in almost every conceivable habitat, they grow symbiotically with fungi in the formation of lichens, they interfere with our adventures in contentment by causing unpleasant odors and tastes in our water supplies. Some algae, like *Chara*, may contribute to the pleasantness of living by preventing the growth of mosquito larvae ("wrigglers") in ponds and pools. Some day we may think it not unusual to read statistics on the productivity of pond, lake, or sea. Algae may be important in ice cream and in various pastries, they serve as ingredients in the preparation of bacteriological media, and they may act as a laxative. Scientific knowledge may be greatly advanced by using algae as subjects of research.

## Chapter XII

# HOW TO COLLECT ALGAE

From the viewpoint of the collector, algae are either visible or not; if perceptible, they may be seen individually or only *en masse*. Algae may grow at the surface of the water or considerably submerged. They may also be geophilous, aerial, epiphytic, epizoic, endophytic, or endozoic. Such things are primary in determining the methods employed in collecting algae.

Some species of algae are bright green in early spring and yellowish to brownish in summer. Planktonic blue-greens may dominate the algal flora only in the fall. *Volvox* and *Synura* usually appear in ponds and lakes at definite seasons, usually early spring; *Cladophora* and *Rhizoclonium* may be found at all times of the year: the one group is annual, the other perennial. Reproductive and vegetative phases of filamentous algae are not often synchronous. Marine algae growing along the seashore and attached to stones are exposed at low tide. When the Septuagint translators made Ecclesiastes opine that "to every thing there is a season," they were putting into the mouth of the Preacher the second criterion for the collector of algae.

If we know something of where algae grow and when they grow abundantly, we are ready to consider the best means of securing them.

Specimens of algae may be collected with a minimum of equipment, although of course quantitative sampling requires apparatus of considerable refinement and complexity.

Suppose we take a collecting trip to some near-by pond just to see how it is done and what we might find. The success of a field expedition is oftentimes more dependent upon what one does before starting than during the excursion. What shall we take with us? A collecting bag is useful, but not necessarily essential: pockets are usually fairly numerous and quite

roomy. In the bag should go a dozen or so small vials or bottles, stoppered and bearing Dennison's gummed labels; forceps, preferably the long ones; two or three larger bottles or jars and perhaps an old tobacco can; a pencil and pocket note book; a hand lens; and a newspaper or two. If the trip

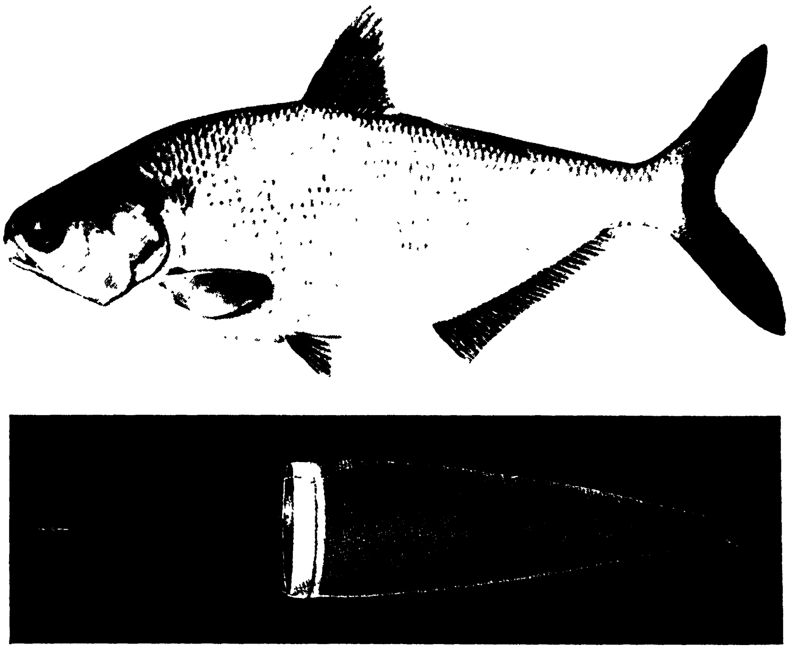


PLATE XLI. Two kinds of townets: the gizzard shad, *Dorosoma cepedianum* (Le Sueur), one of nature's very efficient collectors of plankton; and a mechanical device made of No. 20 standard silk bolting cloth of 173 meshes to the inch. (Upper, courtesy Illinois Natural History Survey and Iowa Conservation Commission. Lower, copyrighted by General Biological Supply House, Chicago.)

is to last over two or three days, particularly if the season be warm, it is necessary to have a supply of preservative. The matter of proper preservation of algae will be mentioned below.

Most of the algae will usually lie quite near the water's edge, but often also just out of reach. Sticks or poles of the

right length to reach the algae are normally available, or one can wade.

Indiscriminate collecting at the pond is likely to be a waste of time. Patches of bright green, slimy algae are often unbranched vegetative filaments of *Spirogyra*, *Zygnema*, or *Ulothrix*. Coarser forms like *Cladophora* and *Pithophora* are soon distinguished by their harsh feel and evident branching. Large forms of *Oedogonium* may have a superficial resemblance to *Cladophora*, except that they are unbranched. If some part of the pond is high in organic matter and not well aerated, such as the outlet of a sewer, blue-green blobs of *Oscillatoria*, *Phormidium*, and *Lyngbya* are to be found quite near shore. The water may be teeming with green balls of *Volvox*, with yellowish diatoms, blue-green *Anabaena*, or red and green *Euglena*. Individually these latter algae are scarcely visible, but the color of the water is a sure indication of the multitude present.

Here is where the hand lens comes in handy. Fill a vial nearly full of water with a small amount of algae and examine with a magnifier. Certain identification is not always possible, to be sure, but valuable information may be secured. One can often make out the spirals of *Spirogyra*, the stars of *Zygnema*, branched and unbranched forms, the setae of *Bulbochaete*, the spores of fruiting filaments, and after a little practice even desmids and diatoms.

Small samples of the desired algae may then be placed in the vials, which should be securely stoppered. Data as to name of pond, date, identity of collector, and approximate spot at which collection was made may be briefly recorded on the label. Sometimes it is desirable additionally to place a number, or other brief information, inside the bottle as a safety device in case the external label should become illegible. If it seems necessary rather fully to record habitat data, the proper references belong in the notebook. It is well to secure material from various parts of the pond because slight differences in $CO_2$ or nitrate content of the water, degree of illumination,

and the accident of spore lodgment may mean different species within small compasses.

The element of uncertainty in knowing just exactly what one has collected is somewhat of a spur for immediate examination, upon return from the trip, under a microscope. The sooner one can analyze his samples microscopically the more likely he is to see the algae unchanged by too long confinement in the bottles. *Volvox* and *Chlamydomonas* may still be churning the water, filaments of *Spirogyra* and *Oscillatoria* continue to slither over the glass slide, and diatoms make zigzag crawls. Best of all, color and variety of chloroplasts are undisturbed.

In general, shallow quiet water, replenished occasionally by run-in from adjacent land, is a particularly favorable habitat for the floating or rarely attached algae. *Cladophora*, *Draparnaldia*, and *Tetraspora*, which remain attached during vegetative development, are more likely to be found on stones, sticks, and submerged macrophytes washed by moving water. Coarser forms of algal weeds, like *Cladophora*, should not be completely scorned by the collector even after he has "learned how to collect." These larger algae together with other submerged plants furnish excellent support for the myriads of small epiphytic forms which are so often overlooked by the amateur.

We have used the bottles, the labels, the corks, the forceps, the notebook, and the hand lens. What of the tobacco tin and the newspaper? Larger masses of filamentous algae are conveniently brought to the laboratory by the simple expedient of squeezing out the water and wrapping the mass in two or three thicknesses of newspaper, or placing in the tobacco can. Too rapid evaporation is thus prevented, and decay of the plants does not set in for several hours.

If one is unable at once to examine the collection, the algae may be kept alive—in fact will grow and reproduce—in a sizable jar of pond water placed near a moderately lighted window.

The collection of plankton algae in concentrated and representative samples is rather effectively accomplished through the capture of certain fishes, tadpoles, and insect larvae. Among the fishes the gizzard shad is perhaps the greatest collector of freshwater plankton known today. The real explanation of what is apparently a high degree of acquisitiveness is merely a matter of food supply. In fact a gizzard shad is in some respects better than a townet. It does not get caught on snags and roots, the string does not break, and the algal collection is very representative of the body of water from which the fish was taken. It is only necessary to catch several young fish and examine their stomachic and intestinal content to secure a proportionate sample of the plankton. Many fishes of course feed on algae only when young and some perhaps never. Mann has called attention to the marine menhaden which is preeminently a diatom feeder and hence an excellent natural collector.

The writer once examined the remains of a recent meal of a single rapidly growing tadpole to find 57* different varieties of algae distributed among greens, blue-greens, yellow-greens, browns, diatoms, and euglenas. Larvae of mayflies, several species of crustaceans, copepods, and many other aquatic denizens consume algae which are readily available to the investigator any time before the animal's digestive processes proceed too far. To prevent such chemical changes, one should make immediate use of some good preservative.

The ideal preservative for algae has not yet been evolved. The chief requisite is an easily obtainable liquid that least alters the appearance of the algae. Some algae are more affected by chemical compounds than are others, particularly as regards color, solubility, and distortion of chloroplasts. Perhaps the one best suited to the needs of the general collector is that worked out by Transeau about 1908–10. It is made up of 6 parts water, 3 parts 95% alcohol, and 1 part 40% commercial formaldehyde (formalin). The addition of a little

* Not a facetious reference to that well known producer of commercial varieties of canned goods.

copper sulfate may keep the algae green for a considerable time.

At the start of the collecting trip each vial should be about one-third filled with Transeau's solution. Adding a quantity of algae will of course dilute the preservative, but this is usually insufficient to lessen its effectiveness. If the samples are to be stored for some time, say in making a herbarium, the addition of a small amount of glycerine is an excellent safety device in preventing complete evaporation of the preservative and consequent desiccation of the algae. Completely desiccated herbarium specimens of algae, however, may be made available for study with considerable satisfaction by the use of a method worked out by L. C. Li. The technique consists in placing the dried algae in a 50 50 mixture of glycerine and Transeau's solution and keeping in a 35 to 45 degree oven for from one to three weeks. Furthermore, immersing in lactic acid and heating gently often brings back the original shape of the cells.

The sampling of marine plankton algae is done in much the same way as in fresh waters and will not be discussed further.

Suggestions for the collection of the larger marine algae have been given by numerous writers over a period of many years. The macroscopic algae of the sea have attracted the attention of navigators from earliest times, and perhaps the use of kelp as a fertilizer on near-shore farms is an ancient practice.

Shore lines are various and each has its own type of algae. The rocky coast with its steep cliffs, the boulders, the lagoons, the salt marshes, the sandy beach, and the tide pools: all are possible and probable habitats for good collecting.

It is important to secure non-mutilated specimens in fruit, if practicable, and showing the general habit of the entire plant. Attached plants should retain their holdfasts. Many algae are strewn along shore after every storm, and often these may be nearly perfect specimens. The plants will usually spoil if placed in other than salt water; sometimes immersion in fresh water for a very brief time ruins the alga. Although many marine forms are kept in excellent shape in the usual

preservatives, the lovely colors of the more delicate algae can scarcely be long retained.

The most practical method of keeping the larger algae is the making of so-called mounts, similar to the ordinary herbarium specimen of flowering plants. F. S. Collins, the Massachusetts rubber manufacturer who became interested in algae as a hobby and who made an outstanding contribution to American Algology, was especially interested in marine forms. Nearly forty years ago he wrote these directions for collectors of seaweeds:—

"When ready to mount, float out the specimens in some large vessel of clean salt water; remove any dirt or foreign bodies; when the plant is too densely branched, trim as needed. Let the specimen assume its natural form in the water; if fresh it will do so readily; slide under it a paper of suitable size, lift so that when taken from the water the plant will remain on it, in the same shape it had in the water. Place the paper on a sloping board to drain for a short time; then lay on drying paper, specimen up; when no more specimens can be placed on the drier, cover all very carefully with a cotton cloth of the same size as the drier. Another drier, more specimens, another cloth, and so on indefinitely.

"The whole is then to be pressed, the same as flowering plants. Driers should be changed after perhaps an hour; then less and less frequently, though oftener than is usual with flowering plants. Cloths should not usually be changed; by reversing the pile, the cloth with all the specimens on it can be readily shifted. Drying paper is the same as used for flowering plants, the heavier the better; for delicate algae heavy blotting paper is rather better, but more expensive. For mounting paper any sufficiently strong kind can be used; standard herbarium paper is excellent; it can be bought ready cut, in full sheets, half, quarter and eighth sizes, which give all usually needed. Ordinary cotton cloth, preferably rather fine, should be used; old is better than new; worn sheets and pillow-cases are as good as anything that can be had.

"When thoroughly dry, most species of algae will adhere

firmly to paper; those that continue unattached should be fastened by a little glue."

So far we have discussed what might be termed the layman's methods of collecting algae. Even so, a great deal may be learned about the algae, along with the satisfaction that comes from exploring a new field of endeavor, with no greater outlay of apparatus than just described. One needs of course aids in the way of published reports, well illustrated, and lists of such references will be given at the end of the book.

There are, however, numerous and sundry devices to aid the specialist. He may desire exactly measured samples of plankton, he may wish to explore the flora at considerable or even profound depths, or he may be interested in the algal productivity at different levels from the surface downward. The quantitative study of ocean algae perhaps began over a half century ago with the introduction of the dragnet.

Samples of plankton are often secured by the use of townets, made from bolting cloth of quite fine mesh (No. 20 is usually used). Such a device samples only the so-called net plankton, not the nannoplankton. The latter is made up of organisms too small to be retained by the finest of townet meshes. If a concentrated but not necessarily quantitative sample of plankton is desired, the net may be fastened by a stout string to a slowly moving rowboat and allowed to "trail along" near the surface of the water. Water passes through the net and the larger organisms are retained and finally washed into the tube at the smaller end of the funnel. One may soon become expert in throwing the net considerable distances from shore— first being certain that the free end of the string attached to the net is secure around a finger— and pulling in at a rate sufficiently rapid to make a surface haul.

Vertical hauls may be made with greater precision. The net is lowered to any desired depth and rapidly pulled up through a definite column of water. It is evident of course that this is not a wholly efficient method. Some of the water never passes through the strainer, the meshes become more and more clogged as the net reaches the surface, and the greater

the supply of plankton the less representative is the haul. The catch secured in this way indicates that the net is from 50–80% efficient.

The quantity of such plankton is usually determined by enumeration. The samples are made up to a uniform volume (say, 20 cc.) and one cc. is transferred to a Sedgwick-Rafter cell. Accurate counts of algae in each cubic centimeter may then be made under the microscope.

The nannoplankton mentioned above is quantitatively studied by taking water samples at definite depths by a so-called water sampler. The algae thus secured are strained through a net, definitely known quantities (or aliquot parts thereof) are centrifuged, and small volume samples enumerated. By simple calculations the number of organisms per liter, per gallon, or per lake is thus secured.

## CHAPTER XIII

# HOW TO STUDY ALGAE

MUCH can be learned of the growth, habits, color, and abundance of algae by field observations, such as those discussed in the preceding chapter. An intimate knowledge of these plants, however, can scarcely be had without the use of a good microscope. Our eyes, though of wonderful design and construction, woefully limit our conception of the world about us especially in the matter of distant objects and tiny particles. Knowledge of the heavenly bodies is gained largely through telescopes, mathematical deductions, and chemical analyses of spectra. The gene and the subdivisions of the molecule and the atom are perhaps in the realm of the submicroscopic, although clever biologists, physicists, and chemists have made them subjects of everyday conversation. If we are then to study algae scientifically, we must do it largely through the use of a microscope.

Algae are best studied, as might be guessed, in a living condition. Much more information as well as exact data may be gathered by observations of the plants unchanged and unharmed by any unnatural environment. This necessitates examination of the material as soon as possible after the collection is made, or the other alternative of growing the algae indoors in as nearly a natural environment as possible. In addition to the microscope one needs slides, cover glasses, cheese cloth, forceps, pipettes, needles, and a table at a window or near a good source of artificial light.

Well-illustrated manuals with simple keys are almost indispensable for the amateur who would investigate the algae. Several years experience with students seem to indicate emphasis, at first, on the genus of the plant. In this way characteristic cell shapes, chloroplasts, growth patterns, and behavior are learned without too much detail. This means

merely that the student's first endeavor is to ascertain, for example, whether the alga is a *Volvox*, a *Spirogyra*, a *Pediastrum*, a *Closterium*, or a *Cladophora*. It is less confusing for the beginner to ignore classification as such. After familiarity with several different genera is gained, the algae become associated into groups almost without effort. Filamentous forms are separated from discs, colonies from one-celled algae, greens from blue-greens, branched from unbranched, and those that move from those that do not. This is not of course what is ordinarily meant by classification, but it is only an easy step from such concepts to other groups and divisions. The diatoms soon seem different from the desmids, and the names green, blue-green, and yellow-green take on a meaningful significance. Order and family differentiation is a matter of a little more perspicacity, but the difficulties are not unsurmountable. Analysis to species should in most cases be attempted only after one is fairly well acquainted with genera.

It is necessary of course that algae be classified. Separate knowledges have come to mankind so rapidly in the last century that even science is in danger of becoming chaotic unless scientists constantly organize and reorganize, classify and reclassify, correlate and recorrelate factual and inferential data. And so almost every alga known has been placed in its separate pigeon-hole. Little pigeon holes together make larger ones, and finally we have an incredibly large unit to which all plants belong: the plant kingdom. How is it made up?

Suppose that we "classify" some alga, say the tiny green ball known as *Volvox globator*, which is merely a Latin binomial meaning "globose roll," or "round ball." (The significance of the Latin words will be referred to later.) We similarly employ the binomial in speaking of "John Smith," only we should say "Smith John" if we were using an exactly parallel case. At any rate *Volvox* is the genus and *globator* is its species.. If we were studying trees, we might refer to *Quercus alba*, white oak: *Quercus* (oak) is the genus and *alba* (white) the species.

Now we soon find out that *Volvox globator* has some very close relatives: *Volvox aureus* (golden roll) and *Volvox per-*

*globator* (almost-globose roll), for example. These three species, along with a few others, constitute the genus, *Volvox*; that is, they are all Volvoxes, but not identical—just as there are black oaks, chestnut oaks, red oaks, white oaks, laurel oaks.

If we examine a collection containing a *Volvox*, we are almost sure to encounter some of its other relatives: not so close as those mentioned above, but evidently similar. Such forms as *Pandorina*, *Eudorina*, *Gonium* are genera in themselves, like *Volvox*. They resemble *Volvox* in such matters as shape, method of locomotion, and definite numbers of cells in a colony. These genera together constitute a family, Volvocaceae. Many other genera of algae are similar to *Volvox*, *Pandorina*, *Eudorina*, and *Gonium* in being flagellated and definitely shaped and in having similar modes of reproduction. This aggregation makes up an order, Volvocales.

A much larger group of genera resemble *Volvox* in having green chloroplasts along with other characteristics. These together form the great class of green algae or Chlorophyceae. Green algae, along with red algae, brown algae, blue-green algae, and diatoms— all algae—make up the subkingdom or division Phycophyta.* Algae, as we have repeatedly said, are plants, and together with oaks and pines, mushrooms and toadstools, mosses and liverworts, ferns and cycads, and all the rest, they form the Plant Kingdom. This relationship is illustrated on the next page (fig. 12).

Now that we have decided that initial emphasis on genera is the simplest method of studying algae, the natural question arises, How do we know, in the first place, the particular genus to which the alga under our microscope belongs? Not so very many years ago identification to genus was very difficult. Only a few people had studied algae critically, and thev were mostly Europeans. Shortly after the turn of the century largely through the impetus given by Frank Shipley Collins— a Massachusetts rubber manufacturer by trade— American

* Phycophyta is not always used in this sense; it is often much restricted, sometimes meaning green algae. The blue-greens are frequently included under Schizophyta, for example. We shall not here attempt to evaluate schemes of classification.

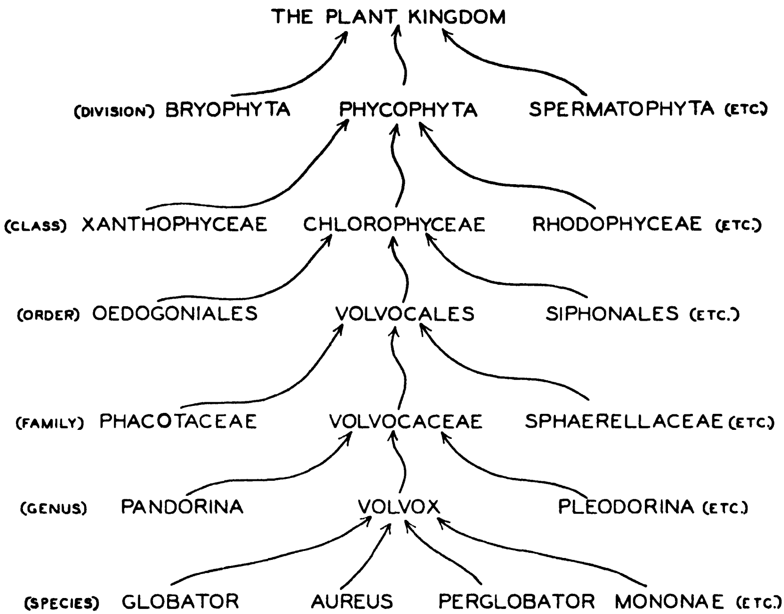



FIG. 12. Diagrammatic representation of the grouping of certain algae into a system of classification. (Read from the bottom up.)

algology had its real start. At any rate the study of algae, especially in America, was soon to become less an item of limited intercourse among a few specialists and more a subject of interest to the scientific public.

To the beginner examining a collection under his microscope, each alga may be considered an "unknown." The specialist, or somebody who knows the plants, may aid the novitiate in several ways. He may simply inform the student by word of mouth that the long thread of cells with green spiral chloroplasts lying at about five o'clock in the field of the microscope is a *Spirogyra*. All such threads may then become associated in the student's mind with *Spirogyra:* he has learned one genus in the algae. Similarly the whole collection, and eventually others, might be analyzed. The chief difficulty with such a procedure is that the specialist may be in New York and the student in San Diego.

Another device is the one in which algae properly named are mounted on special microscopic slides or dried on herbarium sheets. If these can be secured, the student then compares his specimens with the named ones: this is called "matching plants." The scheme works fairly well with large plants that may be seen with the naked eye. The country in fact abounds in fairly well-kept herbaria containing specimens of seed plants and ferns. For the algae, however, identification under a microscope is almost always necessary, the tiny plants undergo profound changes both in liquid preservative and when dried, and to the beginner this presents a very serious handicap, and with some algae an utter impossibility.

A third avenue of approach is much more satisfactory. The specialist may write a clear and comprehensive description of an alga. He may organize all the known characteristics of an algal group into specially constructed numbered statements known as a "key." By careful reading of the key as well as of the descriptions the student may decide what his particular plant may be. If the key is properly constructed and if the description really describes, the identification is fairly certain. There are, unfortunately, some serious pitfalls in this method of study.

The English language is not made up of words sharply delimited and circumscribed. For the most part our language, like Topsy, "just grew." We may speak of a "large" mountain and of a "large" ant. Is a "globose" spore exactly globose, or is it subglobose, depressed-globose, or angularly globose? Is the color of a leaf properly described as green, yellow-green, or greenish-yellow? In fact color has been found to be a rather personal matter, and it is difficult to convey to another by words the exact tint perceived. Words are used relatively, and it is surprisingly unsatisfactory to try to convey to another the exact image one has in mind, not only as regards color but almost everything else.

Descriptions are much less troublesome if accompanied by accurate diagrams, drawings, or photographs. Illustrations furnish perhaps the best and easiest method of transferring

ideas from one person to another. All the characteristics of a particular alga—such as motility, shades of color, and numerous variations—cannot be completely depicted, even in an expert replication. The essential earmarks, however, can be indicated, and difficulties of identification are reduced to a minimum. Manuals containing such illustrations are becoming quite common and fairly readily accessible.

Due to various causes, such as mutations, hybridizations, or mere elusiveness, specimens are frequently found that fit into no known description and that look like no available drawing. One must soon learn to understand monstrosities, depauperate forms, and mutilations. If after due consideration and due care, no likeness can be found to one's specimen, he may regard his alga as something new, a form not previously reported to science. This gives the discoverer the right to select a new name and publish his results in some scientific journal. The first time this happens, the embryo scientist may be considerably thrilled.

The names by which algae are "tagged" seem almost incomprehensible at first. We just noticed that a certain "globose roll" among algae is referred to as *Volvox globator*. The two latin names—the so-called binomial—have been used for many years in botanical and zoological nomenclature. A latin word is supposed to convey the same meaning to an Englishman, a Turk, a Chinese, or an Egyptian—a sort of universal language. All "dressed up" this same globose ball might appear in the books as *Volvox globator* Linnaeus 1758. The plant was discovered and christened in 1758 by that early veteran namer-of-things-biological, Karl von Linnè.

Both generic and specific names used for plants have various origins. The appellations may be descriptive: *Spirogyra*, *Bulbochaete*, *gigantea;* or geographical: *mexicanum*, *americanum*, *canadense;* or ecological: *pratense*, *arctica*, *alpina*, *aquatica;* or in honor of some friend, noted scientist, benefactor, or ruler: *Westella*, *Brittonii*, *Cleveanum*, or in non-algal groups: *Georgia*, *Catharinea*, *Linnaea*, *Coulteri*.

Man is almost innately a collector of things. It may be

postage stamps or fish hooks or rare books or expensive paintings. It may even take the form of prehistoric bones and skulls or rocks of the ages. One individual takes photographs of scenic views or noted personages and gets together an album of many volumes. Another goes to Africa or South America and proudly shows you his game room full of trophies of the hunt and chase. Such a propensity for collectanea may constitute a hobby, a diversion, an inquiry into the little known, a means of making a living, or all of them together. We have museums and art galleries, herbaria and aquaria, botanical and zoological gardens, game and forest preserves, arboretums, and trophy rooms. They serve other purposes, to be sure, but they represent somebody's love for collecting.

* * * *

*This little book has endeavored to make the algae somewhat more familiar to you. They may be studied quite seriously as a matter of scientific inquiry or they make interesting subjects for a hobby or a diversion.*

## GENERAL REFERENCES

(Not intended to be exhaustive, but merely suggestive)


1. Allen, W. E. 1920. *A quantitative and statistical study of the San Joaquin River.* University of California Publication in Zoology. Berkeley, California.
2. Barrell, J. 1917. *Rhythms and measurement of geological time.* Bulletin of the Geological Society of America 28: 745.
3. Bigelow, H. B. 1931. Oceanography. Houghton Mifflin Company.
4. Birge, E. A., and C. Juday. 1922. *The inland lakes of Wisconsin. 1. The Plankton.* Wisconsin Geological and Natural History Survey. Madison.
5. Brown, Helen J. 1935. *Marine algae of commerce.* School Science and Mathematics 35: 803.
6. Brown, William H. 1935. The Plant Kingdom. Ginn and Company.
7. Collins, Frank S. 1899. *To seaweed collectors.* Rhodora 1: 121.
8. Fritsch, F. E. 1934. Structure and Reproduction of the Algae. The Macmillan Company.
9. Hirmer, Max. 1927. Handbuch der Paläobotanik (Pia, J., on Thallophytes). R. Oldenburg, Berlin.
10. Howe, M. A. 1912. *Building of coral reefs.* Science 36: 842.
11. Johnstone, James. 1908. Conditions of Life in the Sea. Cambridge University Press.
12. Kofoid, C. A. 1903 08. *Plankton Studies, IV--V.* Bulletin Illinois State Laboratory of Natural History. Urbana.
13. Morgan, Ann Haven. 1930. Field Book of Pond and Stream. G. P. Putnam's Sons.
14. Morris, H. P. 1932. *Studies on the nutritive value of kelp meal for animal feeding.* Technological Report #5, U. S. Bureau of Fisheries.
15. Roy, S. K. 1927. *How old are fossils?* Field Museum of Natural History Geological Leaflet #9.
16. Russell, E. J. 1923. The Micro-organisms of the Soil. Longmans, Green and Company.
17. Seward, A. C. 1931. Plant Life through the Ages. The Macmillan Company.
18. Smith, G. M. 1933. Fresh-water Algae of the United States. McGraw-Hill Company.
19. Surber, Eugene W. 1932. *Controlling vegetation in fish ponds with sodium arsenite.* Bureau of Fisheries, Investigational Report #11. Government Printing Office.
20. Tiffany, L. H. 1928. *Some economic aspects of the algae.* School Science and Mathematics 28: 581.

21. Tilden, J. E. 1935. The Algae and their Life Relations. University of Minnesota Press, Minneapolis.
22. Tressler, D. K. 1923. Marine Products of Commerce. Chemical Catalog Company.
23. Waksman, S. A. 1932. Principles of Soil Biology. The Williams and Wilkins Company.
24. Welch, P. S. 1935. Limnology. The McGraw-Hill Company.
25. West, G. S., and F. E. Fritsch. 1927. British Fresh-Water Algae. The Cambridge University Press.

(Many of the references above contain unusually complete bibliographies; the reader is referred to these for more intensive studies of the algae.)

# INDEX

(Numbers in bold face indicate illustrations)


Aalaula, 137
*Acanthosphaera*, **38**
*Acetabulum*, 77
*Actinoclava*, 123
Adaptation, 75, 91
Agar, 76, 138
*Agarum*, 74
Agouti, 107
*Ahnfeldtia*, 137
Ai, 100, 105
Akinete, 30, **60**
Alaalaula, 137
*Alaria*, 74, 138, **140**
Algacides, 129, 130
Algae: aerial, 98, 99, 127
  blue-green, 9, 11, 19, **41**, 47, 49, 56, 63, 88, 97, 103, 117, 121, 126
  brown, 9, 11, 47, 74, 117
  chemical composition of, 131, 136
  classification of, 156, 158
  collecting, 146, 160
  definition of, 7, 12
  golden-brown, 9, 11, 47, 56
  green, 9, 11, 47, 56, 63, 76, 88, 121
  harmful, 101, 126, 128
  marine, 7, 65, 70, 79, 137, 140
  nutritive value of, 135, 138
  preservation of, 150
  red, 9, 11, 47, 74, 76, 117
  snow, 49, 90, **92**
  soil, 83, **84**, 143
  yellow-green, 9, 11, 18, 117, 121
Algin, 139
Alginates, 139
*Alysiella*, 106
Amino acids, 18
Amori, 137
*Anabaena*, **48**, 103, 107, 127, 131, 148
Anabaenin, 19, 23
*Anabaeniolum*, **100**, 107
*Anaulus*, **109**
Androsporangium, **32**
Androspore, **32**, 35
Angstrom unit, 43
Animals, versus plants, 5, 31
*Ankistrodesmus*, **38**, 93
Annuals, 52
*Anthoceros*, 103
Antiquity, 82, 110
*Aphanizomenon*, **48**
*Aphanocapsa*, 106
*Aphanochaete*, **10**, 98
*Aphanothece*, **41**
Aplanospore, 30
Archaezoic, 112, 117
*Arthrothamnium*, 138
Assimilation, 23
*Asterionella*, **6**, **58**
Autotrophic organisms, 85
Auxospore, 35, **58**
*Azolla*, 103
*Azotobacter*, 87

Bacteria, 15, 83, 89, 105, 128
*Bambusina*, **54**
*Basicladia*, **100**, 105
*Batrachospermum*, **6**, 59, **60**
Bear, 100
*Biddulphia*, **109**
*Binuclearia*, **10**
*Bornetella*, 77, 120
*Botrydium*, 83, 143
*Botryococcus*, **38**, 121
*Branchipus*, 105
Bromine, 68
*Bulbochaete*, 97, 98, **144**, 148
*Bumilleria*, **84**

Calcium, 23, 68
*Calothrix*, **48**, 77

Carbon dioxide, 14, 15, 52, 69, 88
Carotin, 9, 11
Carpogonium, 74
Carrageen, 136
*Carteria*, 106
*Caulerpa*, 71, 77
Cell division, 27 30
Cenozoic, 112, 117
Centrifuge, 62
*Centritractus*, **38**
*Cephaleuros*, **100**, 102, 103, 127
*Ceramium*, 76
*Ceratium*, **6**, **40**, 82
Ceylon moss, 76
*Chaetophora*, **60**, 61
*Chaetosphaeridium*, **10**
*Chamaesiphon*, **62**
*Chara*, 113, 115, 133, **141**, 145
*Characiopsis*, **38**, **100**, 103 105
*Characium*, **38**, 103
Charophyceae, 117
*Chlamydomonas*, 62, **84**, **92**, 93, 110, 149
*Chlorella*, **38**, 103, 105
*Chlorellopsis*, **114**
Chlorine, 68
*Chlorochytrium*, 102, 103, 106
*Chlorococcum*, **84**
Chloroplasts, **16**
Chlorophyceae, 11, 117, 158
Chlorophyll, 9, 11, 13
*Chlorosphaera*, 93
*Chondrus*, 76, 136
*Chorda*, 74
*Chroococcus*, **41**, 82, 103
Chrysophyceae, 11
Cilia, 30, **40**
*Cladophora*, 27, 46, 56, 59, **60**, 76, 90, 97, 103, 107, 131, 146, 148
*Closterium*, **6**, **16**
*Coccobotrys*, 103
*Coccomyxa*, 103
*Cocconeis*, **58**, **80**, 98
*Codium*, 77, 120, 137
*Coelastrum*, **38**
*Coelosphaerium*, **41**, 107
*Coleochaete*, **10**
Condensation, 17
Conjugation, **8**, **22**, 35
Contamination, 127, 129
*Convoluta*, 106
Copepods, 7, 81, 103, 134, 139
Copper sulfate, 129
*Corallina*, 76
Corals, 111, 115
*Coscinodiscus*, **80**, **109**, 123
*Cosmarium*, **6**, **16**, **54**
*Costaria*, 74
Counting cell, 62, 154
*Crucigenia*, **6**, **38**
Crustaceans, 105, 139
Cryoalgae, 49, 90
Cryoplankton, 90
*Cryptozoon*, 119
Culture media, 85, 86
*Cyanoderma*, **100**, 105
Cycad, 103
*Cyclonexis*, **40**
*Cyclorinus*, 120
*Cyclotella*, **80**
*Cylindrocapsa*, **10**
*Cylindrospermum*, 97
*Cymbella*, **58**
Cystocarp, 75

*Dactylococcopsis*, **100**
*Dactylococcus*, **84**
*Dasycladus*, 77
Death, 25, 126
*Debarya*, **144**
*Delesseria*, 76
*Dermocarpa*, **100**
Desiccation, 99, 103, 151
*Desmidium*, **54**
Desmids, **6**, **16**, 53, **54**, 56, 148, 156
Diatomaceous earth, 81, 123, 143
Diatomophyceae, 11, 117
Diatoms, **6**, 28, **29**, 35, 47, 49, 56, **58**, 63, 79, 88, 93, **94**, 97, **109**, 131, 133, 135, 148, 156
*Dictyosphaerium*, **38**
*Dimorphosiphon*, 120
*Dinobryon*, **6**, **38**
Dinoflagellates (see Dinophyceae)
Dinophyceae, 11, 82, 117, 122, 135
*Diplopora*, **124**
Dog days, 3, 7
Dormancy, 24, 30, 110

*Dorosoma*, **147**
*Draparnaldia*, **4**, **10**, 61, 149
Duckweeds, 47
Dulse, 136
*Dunaliella*, 91
Dwarf male, **32**, 35

*Echinosphaerella*, **38**
*Ecklonia*, 76
Economic products, 76, 136
Eggs, **32**, 33, **73**
Endophyte, 102, 103
Endozoon, 105, 126
Energy, 14, 22, 23
*Enteromorpha*, 77
*Entocladia*, 103
*Entogonia*, **109**
*Entophysalis*, **41**
Ephemerals, 52
Epilimnion, 50
Epiphyte, 98, 127
*Epiphyton*, 120
Epivalve, 28
Epizoon, 103
*Euastrum*, **16**, **54**
*Eucapsis*, 28, **41**
*Eudorina*, **40**
*Euglena*, 19, **40**, 56, 62, 148
Euglenophyceae, 11
*Eunotia*, **58**

Fat synthesis, 14, 17, 23
Fatty acids, 17
Fertilization, 33
Fertilizers, 142
Fishes, 129, 133, 139, 150
Flagella, 23, **40**
Florideae, 19
Food chains, 14, 23, 133, 134
Foods, 13, 17, 19, 21, 23, 59, 132, 135
Foraminifera, 115
Fossilization, 111, 112
Fossils, 81, 109, 111, 117
*Fragilaria*, **6**, **58**
*Franceia*, **38**
Fucoxanthin, 9, 11
*Fucus*, **71**, 73, 76, 97, **140**
Fungi, 83, 103, 117, 128
Funori, 137

Gamete, **31**, 35
*Gelidium*, 76, 137
*Geminella*, **10**
Geological:
  ages, 112, 117
  eras, 112, 117
  periods, 112, 117
  time clocks, 108
  time scale, 112
Germination, 22, 23, 25
*Girvanella*, 119
Gizzard shad, 134, **147**, 150
*Gloeocapsa*, 82, 103, 115, 120
*Gloeocapsamorpha*, 119
*Gloeocystis*, **38**, 103
*Gloeotaenium*, **38**
*Gloeothece*, **41**, 115
*Gloiopeltis*, 76, 137
Glycerine, 17
Glycogen, 19, 23
Glycoprotein, 19
*Golenkinia*, **38**
*Gomphonema*, 46, **58**, 97
*Gomphosphaeria*, **41**
*Gongrosira*, 46, **84**, 106
*Gonium*, **40**
*Gonyaulax*, 82
*Gracilaria*, 76
Grass, 3, 14, 21, 65, 79, 82
Growth, 21, 23, 46
*Gyrophora*, **104**
*Gyrosigma*, **58**, **109**

Hake, 134
*Halimeda*, 77, **115**, 120
*Haliseria*, 137
*Halosphaera*, 82
*Hantzschia*, **84**
*Hapalosiphon*, **48**
Heleoplankton, 42
Hemicellulose, 138
Herbarium specimens, 151, 152, 159
Holdfast cell, **32**, 59, 73
*Holopedium*, **41**
Hosts, 96, 102, 105, 106
Huluhuluwaeua, 137
*Hyalotheca*, **54**
*Hydra*, 105

*Hydrodictyon*, **60**
Hypolimnion, 50
Hypovalve, 28

Ice cream, 138, 145
Iodine, 139
Irish moss, 76
Iron, 23

Kelp:
- bladder, 71
- bull, 71
- elk, 72
- giant, 7, 9, 30, 72
- ribbon, 71

Keys, 155, 159
Kiki, 137
*Kirchneriella*, 129
Kumbu, 137

*Lagerheimia*, **38**, **92**
Lakes:
- dystrophic, 51
- eutrophic, 51
- oligotrophic, 51
- vs. ponds, 37

*Laminaria*, 30, **73**, 74, 76, 138, 140
Laver, 136
Laxative, 138, 145
*Lemanea*, 59
*Leptogium*, **100**
*Lessoniopsis*, **79**
Leucosin, 19
Lichens, **100**, 103, **104**, 117
Life, 24
Light, 14, 42, 44, 47, 70
Limestone quarry, 119
Limnoplankton, 42
Limu, 136
*Lithophyllum*, 76, **122**
Lithophyte, 97
*Lithothamnium*, 76, 115, **118**, 119, 120
Locomotion, 23
*Lyngbya*, **48**, 77, 98, 106, 148

*Macrocystis*, 30, 72, 76, **140**
Magnesium, 13, 23, 68
*Marssoniella*, **41**
*Melosira*, **58**
*Merismopedia*, 28, **41**, 82
*Mesotaenium*, 93
Mesozoic, 112, 117, 122
*Micrasterias*, **16**, **54**
*Microcystis*, **6**, **41**, 98, 103, 127, 131
Microorganisms, 83, 85, 107
Microscope, 3, 6, 8, 94, 155, 157
*Microspora*, **4**, **10**, 83
*Microthamnion*, **84**
Mineral salts, 17, 53, 87, 102, 131
*Mitcheldeania*, 121
*Monostroma*, 77
Mosquito larvae, 145
*Mougeotia*, **26**, 98, 107, **144**
Myxophyceae, 11, 117

Names, 160
Nannoplankton, 62, 153
*Navicula*, **58**, **80**, **84**, 97
*Nemalion*, 74, **75**
*Nephrocytium*, **38**
*Nereocystis*, 30, **66**, 71, 76, 136, **140**
*Netrium*, **16**
Nitrates, 14
Nitrogen, 17, 23, 88, 131
*Nodularia*, 88
*Nostoc*, **48**, 83, **84**, 88, 93, 97, 103, 136
Nucleus, 27

*Ochromonas*, **40**
Odors: fish, 128; marsh, 128; pig-pen, 128
*Oedocladium*, **144**
*Oedogonium*, **4**, **6**, 17, 27, **32**, 93, 97, 107, 136, 143, **144**, 148
*Oocystis*, **38**, 55, **92**
Oogonium, **32**, 33, **141**
Oospore, **8**, **32**, 33, **73**, **141**
*Ophiocytium*, **38**
*Ortonella*, 121
*Oscillatoria*, **48**, 77, 83, 97, 148
*Oscillospira*, **100**, 106
*Ottonosia*, **114**
Oxidation, 23, 69, 128
Oxygen, 15, 68, 130
Oysters, 133

*Palaeporella*, 120
Palapahakou, 137

Paleozoic, 112, 117, 121
*Palmella*, 103
*Pandorina*, **40**
Paper, 142
*Paramecium*, 105
Paramylon, 19, 23
Parasite, 103, 107
*Parmelia*, **104**
Parthenogenesis, 33
Pastries, 138, 145
*Pediastrum*, **6**, **38**
*Pelagophycus*, 72, 76, **78**, 140
*Peltigera*, **100**
*Pelvetia*, **72**
*Penicillus*, 77
Pentosans, 131, 138
Perennials, 52
*Peridinium*, **40**, 56, 82
Periodicity, 49, 52, 63
Pfitzer's law, 28
Ph, 55
*Phacotus*, **40**
*Phacus*, **40**
Phaeophyceae, 11, 117
*Phormidium*, **48**, **62**, **84**, **92**, 106, 148
Phosphates, 14, 17
Phosphorus, 23
Photoelectric cell, 46
Photosynthesis, 15, 19, 52, 69, 70, 87, 106, 145
Phycocyanin, 11
Phycoerythrin, 9, 11, 70
*Phycopeltis*, 103
Phycophyta, 157
Pigments, 9, 11
*Pila*, 121
*Pithophora*, 30, **60**, 148
Plankton, **38**, 39, **40**, 41, **58**, 61, 130, 133, 153
Plants, versus animals, 5, 31
*Platydorina*, **6**, **40**
*Pleodorina*, **40**
*Pleurococcus*, **10**, 90, **92**, 98, 99, 103
*Pleurodiscus*, **144**
*Pleurotaenium*, **6**, **54**
*Plumaria*, 76
Poisons, 127, 129
*Polysiphonia*, 76
*Polytoma*, **40**
Ponds, 37
*Porphyra*, 76, 136, 137
*Postelsia*, 30, **79**
Potamoplankton, 42, 61
Potassium, 23, 68, 139
*Prasiola*, **92**, 99, 103
Preservatives, 150, 151
*Primicorallina*, **124**
*Proceratium*, 82
Protein synthesis, 14, 18
Proterozoic, 112, 117
Protista, 7
*Protococcus* (see *Pleurococcus*)
*Protoderma*, 93
Protoplasm, 23
Protoplast, 31, 35
Protozoa, 83, 105
Psychozoic, 112
*Pteromonas*, **92**
*Pterygophora*, 72
Pyrenoid, 17
*Pyxidicula*, 122, **124**

Radiation, 42, 44, 46
*Raphidonema*, **92**, 93
Red Sea, 11, 82
Reduction, 17
Reefs:
  algal, 116
  coral, 115, 116
Reproduction, 23, **31**, **32**, 34, **73**, 75
Respiration, 23, 52, 129
*Rhabdodema*, **80**
*Rhizoclonium*, **60**, 90, 103, 146
*Rhizosolenia*, **58**
*Rhododendron*, 100
Rhodophyceae, 11, 117, 158
*Rhodymenia*, 76, 136
Rivers, 57
*Rivularia*, **6**, 77, 97, 103
Rockweed, 73
Rotifers, 103, 107

Sargasso Sea, 65
*Sargassum*, 66, **67**, 137
*Scenedesmus*, **38**, **84**, 86, 129
*Schizomeris*, **10**

*Schroederia*, **38**
*Scotiella*, **92**, 93
*Scytonema*, 98, 103
Sea:
elements in, 68
kale, 136
lettuce, 27
mosses, 74
orange, 72
otter's cabbage, 30, 71
palm, 30
pumpkin, 72
Ordovician, 120
Sea water, composition of, 69
Seatron, 136
Seaweeds, 7, 65, 70, 138, 142
Secchi's disc, 46
*Selenastrum*, **38**
Silicon, 23, 68
*Simonsiella*, **100**, 106
*Sirodotia*, **60**
Sloth, three-toed, 100, 105
Sodium, 68, 130, 139
Soil, 83
*Solenopora*, 120, 121, **124**
*Sorastrum*, **38**
Spectrum, 42, 44
Sperms, **8**, **32**, 33, **73**
*Sphaerella*, **40**
*Sphaerocodium*, 120
*Sphaerozosma*, **54**
*Spirogyra*, **4**, **8**, 17, **22**, 35, 56, 98, 107, 131, 136, 143, **144**, 148
*Spirotaenia*, **54**
*Spirulina*, **48**
*Spondylosium*, **54**
Sponges, 106
*Spongiostroma*, 121
*Spongocladia*, 106
Spore, **8**, **16**, **22**, 24, 88, **124**
Starch synthesis, 14, 17, 23
*Staurastrum*, **16**, **54**
*Stentor*, 105
*Stephanodiscus*, **6**, **58**
*Stephanopyxis*, **124**
*Stichococcus*, **10**, 45, **84**
*Stigeoclonium*, **6**, **60**, 97
*Stigonema*, **48**, 103
*Stipitococcus*, 98, **100**
*Stomatochroon*, 101
Streams, 57
*Struvea*, 106
Suchi, 137
Sugars, 14, 15, 23
Sulphates, 14, 17, 68
Sulphur, 17
*Surirella*, **58**, **80**
*Synchytrium*, 102
*Synedra*, **58**, 103
*Synura*, **40**, 146

*Tabellaria*, **58**
Tadpole, 133, 134, 139, 150
Temperature, 47, 69, 90, 94
*Tengusa*, 137
*Tetraedron*, **38**
*Tetraspora*, 61, 98, 149
*Tetrastrum*, **38**
*Thamnocladus*, **124**
*Thamnoclonium*, 106
Thermocline, 50, 61
Thermopile, 46
Time clock, 108
Time table, 112
Townets, 62, **147**, 153
*Trachelomonas*, **40**, 55
Transeau's solution, 150
*Trentepohlia*, 99, 103, **144**
*Tribonema*, **60**, 143
*Trichodesmium*, 82
Trichogyne, 74
*Trichophilus*, 105
*Trinacria*, **80**
*Triploceras*, **54**
*Triploporella*, **124**
*Trochiscia*, **38**, **92**
Turbidity, 45, 131
Turtles, 105

*Udotea*, 77
*Ulothrix*, **4**, **10**, **31**, 56, **84**, 93, 97, 148
*Ulva*, 27, 77, 131, 136, 137
*Urococcus*, 103
*Uroglena*, 129
*Uroglenopsis*, **40**

*Vaucheria*, **4**, 18, **34**, 59, 83, 90, 98, 107

Vitamins, 23, 65, 139
Volutin, 19
*Volvox*, **8**, **40**, 56, 98, 107, 131, 146, 148, 156

Water, 14, 15
Water bloom, 39, 97, 122, 130
Wawahiwaa, 137
*Westella*, **38**

Xanthophyceae, 11, 117, 158
Xanthophyll, 9, 11

Zoospore, **10**, 30, **31**, **32**, **73**
*Zygnema*, **26**, **144**, 148
*Zygnemopsis*, **144**
Zygospore (Zygote), **22**, **26**, **31**

*This Book*

# ALGAE

*The Grass of Many Waters*

*was set, printed and bound by The Collegiate Press of Menasha, Wisconsin. The type face is Century Schoolbook. The type page is 24 x 42 picas. The Text paper is 80 pound White Port Tobacco Enamel. The jacket is 65 pound Gray Neptune. The binding is Bancroft Eton No. 265.*

*With THOMAS BOOKS careful attention is given to all details of manufacturing and design. It is the publisher's desire to present books that are satisfactory as to their physical qualities and artistic possibilities and appropriate for their particular use. THOMAS BOOKS will be true to those laws of quality that assure a good name and good will.*